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ABSTRACT

Designed for tenth-grade students, this activity book contains sixty-three electrical experiments. Experiments focus on topics such as the direction of flow of electricity in an electric circuit, comparison of heating effect using different amounts of current, comparison of heating effects of electric current in conductors of different sizes, and connecting and reading a voltmeter. Each experiment follows a typical format that includes the following parts: purpose, materials used, procedure, questions, and references. (IRA)

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CONNECTICUT STATE DEPARTMENT OF EDUCATION
DIVISION OF VOCATIONAL EDUCATION
HARTFORD

ARMORIAL BEARINGS OF STATE OF CONNECTICUT

ELECTRICAL EXPERIMENTS

VT-214-10-1

PART ONE

GRADE 10

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
NATIONAL INSTITUTE OF EDUCATION

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Experiments 1-63

Rev. 9/77

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Electrical Experiments

Experiment No. 1
Page 1 of 2

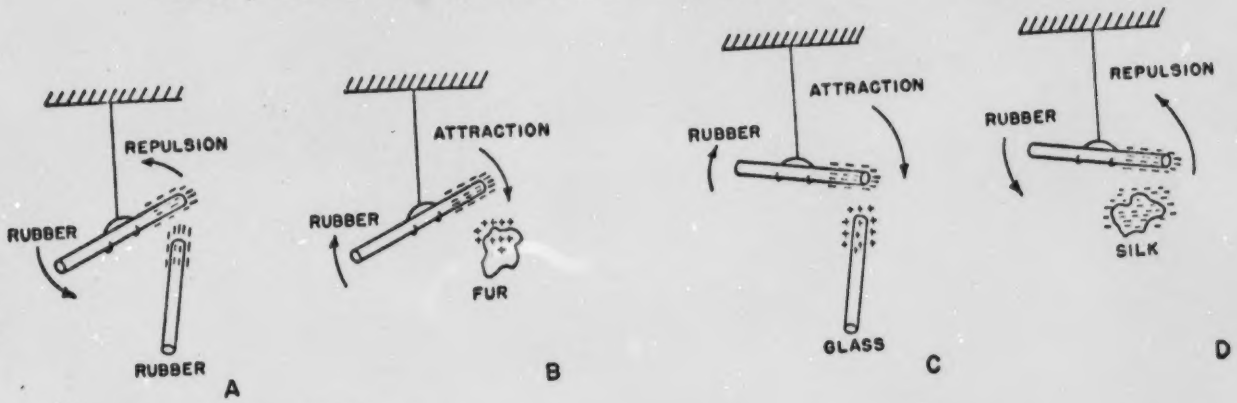
Electrostatic Charges

PURPOSE:

To discover what happens, if anything, when positive objects are rubbed with negative objects.

MATERIALS USED:

Wire stirrup, stand, glass rod, hard rubber rod, wool, silk, amber, sealing wax, rosin and sulfur.



EXPLANATORY NOTES:

Items from list A, will attract items from list B.
Two items from list A repel each other.
Two items from list B repel each other.

List A	List B
Glass (rubbed on silk)	Hard rubber (rubbed on wool)
Glass (rubbed on wool)	Sulfur (rubbed on wool)
Wool (rubbed with sealing wax)	Sealing wax (rubbed on silk)
	Sealing wax (rubbed on wool)

PROCEDURE:

Charge two hard rubber rods by rubbing them with fur. Place one horizontally in a wire stirrup suspended from the stand. Hold the second rod near the suspended rod. Observe that there is repulsion between them.
Repeat the experiment, using materials from list A in the stirrup, and placing items from the B list near them. Continue experiment until you understand there is a difference between positive and negative charges.

Experiment No. 1
Page 2 of 2

QUESTIONS:

1. Explain what you observed in this experiment.
2. Is it possible to make the repulsion or attraction stronger at times? If so, how was this accomplished?
3. Were some items easier to charge than others? If so, list them.
4. Is it possible to produce charges by liquids?

REFERENCES:

Fundamentals of Electricity - McDougal	Pages 6-10
Practical Electricity - Swoopes	Pages 1-3
Direct Current Fundamentals - Loper	Pages 1-2

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 2
Page 1 of 1

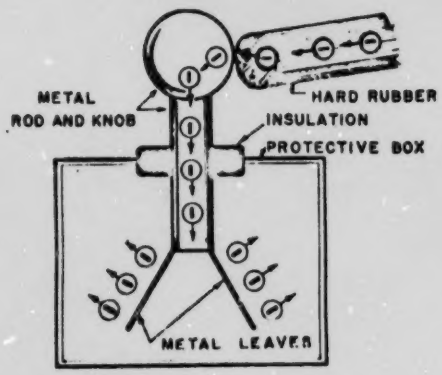
Electrostatic Induction

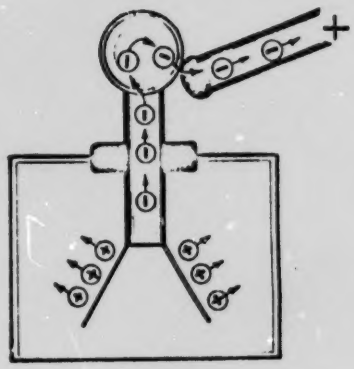
PURPOSE:

To discover what happens when a charged object is placed near an object that is not charged.

MATERIALS USED:

Electroscope, hard rubber rod, glass rod, wool, silk and aluminum foil.





PROCEDURE:

Cut strips of aluminum foil and place in the electroscope rod. Rub the hard rubber rod with wool and hold near the electroscope. Notice the action of the aluminum foil strips. Repeat with the glass rod, rubbing it with silk. Again notice the action of the aluminum foil strip.

QUESTIONS:

1. What was the action of the aluminum foil strips when the hard rubber rod was placed near the electroscope?
2. What different action, if any, took place when the glass rod rubbed with silk, was placed near the electroscope?
3. When the hard rubber rod was rubbed with wool, there was a transfer of electrons. Do they travel toward the rod or the wool?
4. What is the rule of force for positive and negative charges?

REFERENCE:

Practical Electricity - Swoope's	Pages 11-18
Fundamentals of Electricity - McDougal	Pages 5-11
Direct Current Fundamentals - Loper	Pages 18-23

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CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 3
Page 1 of 2

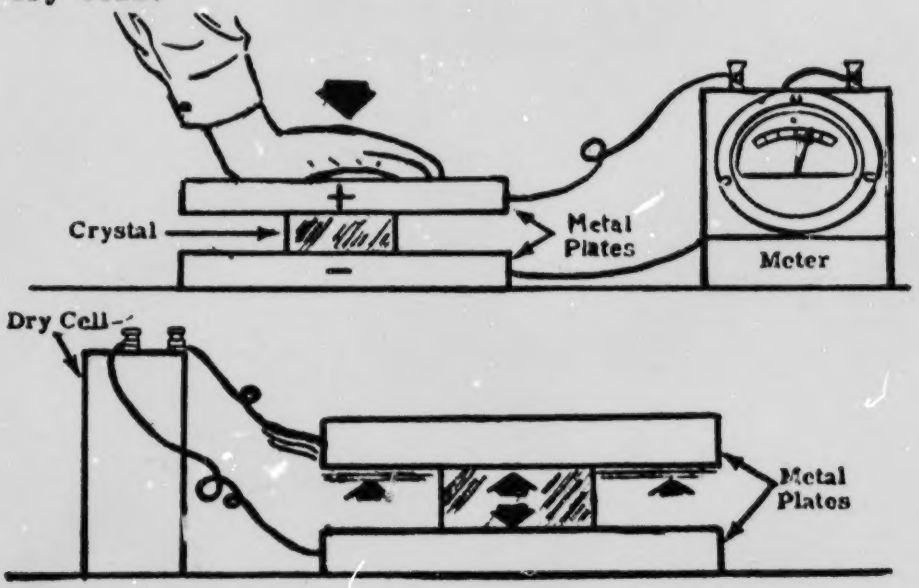
The Pressure Method of Producing Electricity

PURPOSE:

To discover what happens when certain crystal materials are placed between two metal plates and a pressure is exerted on the plates.

MATERIALS USED:

Two metal plates, quartz, tourmaline, Rochelle salts, crystals, center reading galvanometer and dry cell.



PROCEDURE:

Connect as shown in above sketch.
Place heavy object on the upper steel plate and observe meter reading.
Repeat, using the hand to apply pressure. Again observe meter reading.

EXPLANATORY NOTES:

The crystal can be used to convert electrical energy to mechanical energy, by placing a dry cell across the plates, as the crystal will expand and contract, depending on the amount and type of the charge.

Experiment No. 3
Page 2 of 2

QUESTIONS:

1. What did you observe when a heavy object was placed on the upper plate? Did the meter react differently when the hand instead of a heavy object was used for pressure?
2. What factor decides the amount of deflection on the meter?
3. Name several pieces of equipment that use this method.

REFERENCES:

Direct Current Fundamentals - Loper	Pages 168
Basic Electricity - Vol. 1 - Rider	Pages 1-19

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Electrical Experiments

Experiment No. 4
Page 1 of 2

The Heat Method of Producing Electricity

PURPOSE:

To discover what happens if anything, when heat is applied at the junction of two dissimilar metals (the other end remaining at room temperature).

MATERIALS USED:

#18 P.E. copper wire, #18 iron wire, galvanometer, alcohol torch, copper strip and iron strip.

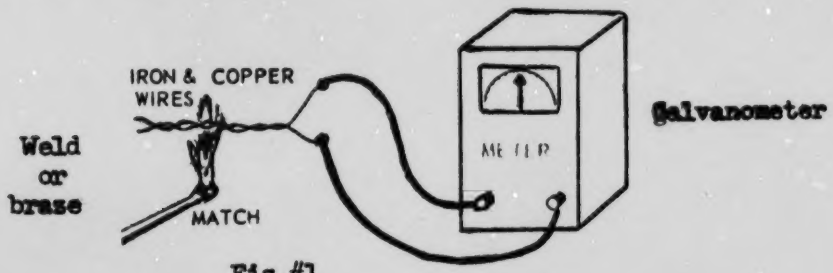


Fig.#1

PROCEDURE:

Tightly twist together (weld if possible) a piece of #18 copper wire about 3 feet long, and a piece of #18 iron wire of about the same length. Connect a galvanometer across the free ends as shown in Fig. 1. (Have the wires between the junction and the galvanometer insulated from each other). Note the position of the galvanometer needle.

Apply heat at the junction of the wires. Be sure that the heat is applied only at the junction, because it is essential that the free ends of the galvanometer remain at room temperature. Carefully watch the needle of the galvanometer as the junction becomes warmer. Continue heating the junction until red hot. Allow the junction to slowly cool, watching the needle of the galvanometer all the while.

Experiment No. 4
Page 2 of 2

QUESTIONS:

1. Explain in detail what you observed to take place in this experiment.
2. Was the action, if any, more or less as the junction became hotter? Explain.
3. Name all the methods with which you are familiar, for producing an e.m.f.

REFERENCES:

Basic Electricity - Marcus	Pages 241-243
Practical Electricity - Swoope	Pages 284-286
Basic Electricity - Vol. 1 - Rider	Page 1-20

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 5
Page 1 of 2

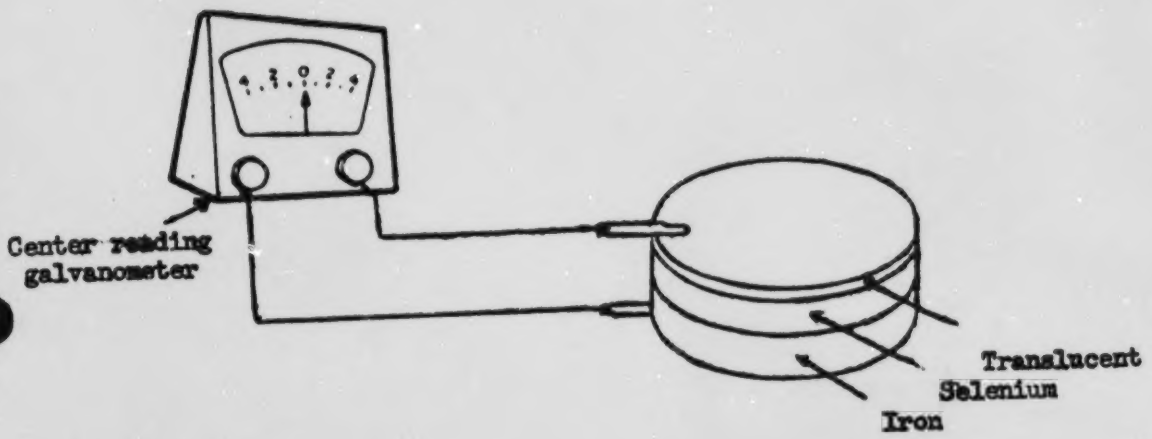
The Light Method of Producing Electricity

PURPOSE:

To discover what happens when light strikes certain materials.

MATERIALS USED:

Iron, selenium alloy, translucent material, light source, center reading galvanometer.



PROCEDURE:

Lay the iron on a table and place a piece of selenium alloy on top. Now place the translucent material on the selenium. Connect one lead of the meter to the iron and one lead to the translucent material. Shine the light source on the translucent material and notice the action of the meter. Repeat by placing the translucent material on the bottom, selenium in the middle and the iron on top. Shine the light source on the iron and notice the action of the meter, if any.

Repeat by placing the selenium on the bottom, the iron in the middle and the translucent material on top. Shine the light source on the translucent material and notice the action, if any, of the meter.

Experiment No. 5
Page 2 of 2

QUESTIONS:

1. When the light was focused on the selenium alloy, through the translucent material, what action did you observe on the meter?
2. What caused the meter to act as it did when the light was focused on the iron?
3. What caused the meter to act as it did when the light was focused on the translucent material, with the iron in the middle?
4. Name several ways this principle can be applied.

REFERENCES:

Basic Electricity - Vol. 1 - Rider	Pages 1-21-1-22
Direct Current Fundamentals - Loper	Page 169

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 6
Page 1 of 2

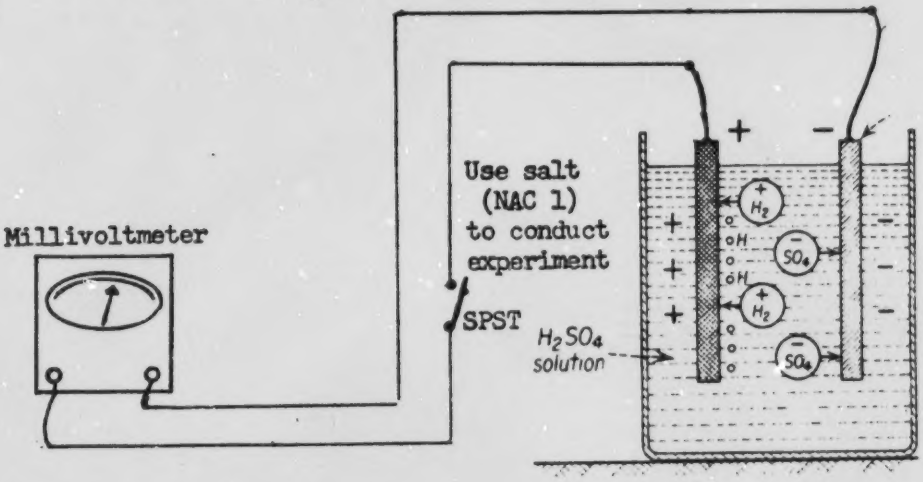
How Chemical Action Produces Electricity

PURPOSE:

To discover what happens, if anything, when two dissimilar metals are immersed in a jar of salt water solution.

MATERIALS USED:

Two strips of copper, two strips of zinc, dilute sulphuric acid, salt, battery jar and cap, D.C. millivolt meter, SPST knife switch.



PROCEDURE:

Fill the glass jar three fourths full with water, and add plain salt. Immerse the two strips of copper in the liquid in the glass jar. Have them separated as shown in sketch. Close the switch. Note the action, if any, of the voltmeter needle.

Repeat, using two zinc strips.

Repeat, using a strip of copper and a strip of zinc.

QUESTIONS:

1. When the two similar strips of copper wire were immersed in the salt solution, did the needle on the voltmeter deflect?
2. When the two similar strips of zinc were immersed in the salt solution, did the needle on the voltmeter deflect?

QUESTIONS (Continued)

3. When the copper strip and the zinc strip were immersed in the salt solution, did the needle on the voltmeter deflect?

4. (a) Was the mechanical construction of the circuit outside the glass jar the same for each of the tests you performed?

   (b) How do you account for the fact that either two copper strips or two zinc strips immersed in the salt solution causes no electricity to flow through the voltmeter, while a strip of copper and a strip of zinc immersed in the salt solution produces electricity?

5. Is electromotive force needed to send electricity through a conductor? Explain.

REFERENCES:

Basic Electricity - Marcus	Pages 216-224
Swoope's Practical Electricity	Pages 70-71

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 7
Page 1 of 2

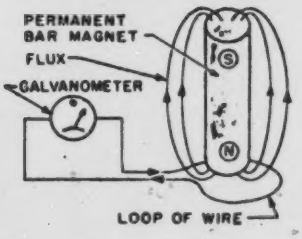
How Magnetic Action Produces Electricity

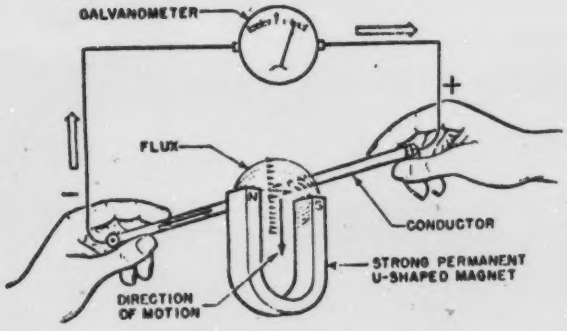
PURPOSE:

To discover what happens, if anything, when wires cut magnetic fields.

MATERIALS USED:

Bar magnet, horseshoe magnet, center reading galvanometer and wire.





PROCEDURE:

Connect a single strand of wire, two feet long, to the galvanometer. With the wire suspended from the table, move the magnet back and forth past the wire, and note the action of the meter.

Note the action as you move the magnet down and also as you move it up.

Repeat by having the magnet stationary and moving the wire. Note the action of the meter as you move the wire up and down.

QUESTIONS:

1. How did the meter react with the wire stationary and the magnet moving?
2. How did the meter react with the magnet stationary and the wire moving?
3. Did the meter react the same the second time as it did the first time?
4. How can we increase the amount of deflection of the meter movement?
5. Name several ways this principle can be applied.

Experiment No. 1
Page 2 of 2

QUESTIONS:

1. Explain what you observed in this experiment.
2. Is it possible to make the repulsion or attraction stronger at times? If so, how was this accomplished?
3. Were some items easier to charge than others? If so, list them.
4. Is it possible to produce charges by liquids?

REFERENCES:

Fundamentals of Electricity - McDougal	Pages 6-10
Practical Electricity - Swoopes	Pages 1-3
Direct Current Fundamentals - Loper	Pages 1-2

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 8
Page 1 of 2

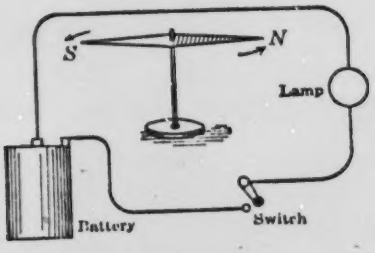
Direction of Flow of Electricity in an Electric Circuit

PURPOSE:

To discover whether or not electricity has a direction of flow.

MATERIALS USED:

Compass, bell wire, dry cell, knife switch and 3V lamp.



PROCEDURE:

Part 1: Place a compass, face up, on a table or bench, making sure there is no iron near the compass. Note the position of the compass needle. Take a piece of bell wire about two feet long and lay it on top of the compass. Have the wire parallel with the magnetic needle of the compass. Touch the ends of the bell wire to the terminals of a dry cell as shown in Fig. 1. Note in which direction the compass needle deflects.

Part 2. Without disturbing that part of the wire passing over the compass, interchange the wire connections at the dry cell as shown in Fig. 2. Again note in which direction the compass needle deflects.

EXPLANATORY NOTES:

Electricians have agreed to assume that the electricity leaves the dry cell at the outer terminal and after passing through the wire, returns to the center terminal of the dry cell. The arrows in Fig. 1 and 2 indicate the direction the electricity is assumed to flow. The center terminal of the dry cell is called the positive (+); while the outer terminal is called the negative (-). As you will find later, the direction in which the electricity is flowing in a wire (that is the polarity of a circuit) must often be found in order to make proper connections so that certain electrical devices will operate. There are various methods for determining polarity (positive and negative) of a circuit.

Experiment No. 8
Page 2 of 2

QUESTIONS:

1. Describe fully what you observed while performing this experiment.
2. Did your observations give any proof for supposing that electricity has a direction of flow? Explain.
3. What fact have you discovered in this experiment?
4. What is your understanding of the following terms?
   (a) Polarity (b) Positive (c) Negative

REFERENCES:

Basic Electricity - Marcus	Pages 55-57
Practical Electricity - Swoope's	Pages 43-45

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 9
Page 1 of 2

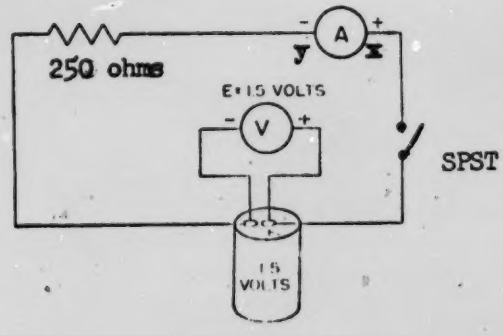
Direction of Flow of Electricity in an Electric Circuit

PURPOSE:

To discover what difference, if any, the direction of flow of electricity in a conductor causes in the action of the needle of a milliammeter.

MATERIALS USED:

Bell wire, dry cell, 250 ohm resistor, center reading milliammeter, terminal patch board, knife switch.



PROCEDURE:

Connect milliammeter into circuit as shown in Fig. 1. Positive terminal to the "X" lead, negative terminal to the "Y" lead.

With the switch open, note the position of needle. Close switch. Again note in which direction the needle deflects. Open switch.

Interchange the wires "X" and "Y" on the terminals of the meter. Again note in which direction the needle deflects. Close switch. Again note direction of needle deflection.

QUESTIONS:

1. In what direction did the needle deflect when the positive terminal was connected to the "X" lead and the negative terminal to the "Y" lead?
2. In what direction did the meter deflect when the wires were interchanged at the terminals of the meter?
3. Explain, in your own words, what fact you have discovered in this experiment.

QUESTIONS (Continued)

4. What do you think is the reason for the difference, if any, in the behavior of the needle of the meter when the wires "X" and "Y" were interchanged?
5. Name several methods that can be used to check direction of current flow.

REFERENCES:

Swoope's Practical Electricity	Pages 43-45
Marcus Basic Electricity	Pages 83-85

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 10
Page 1 of 2

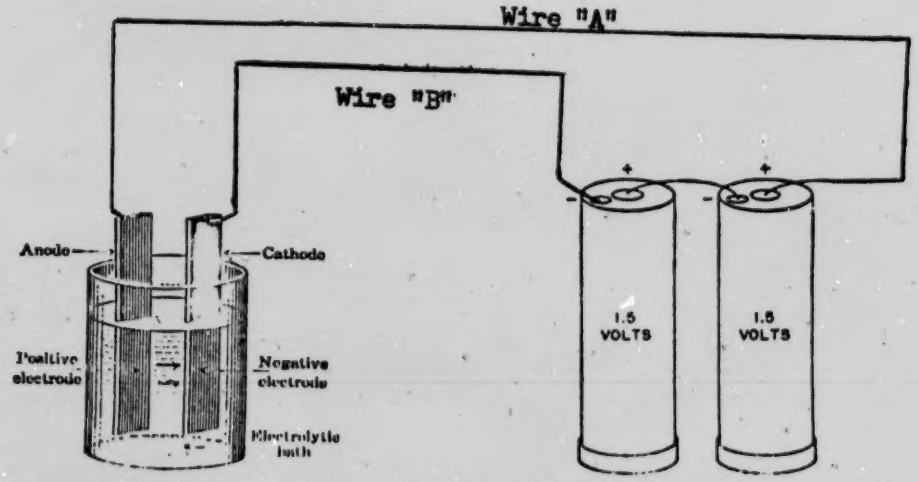
Direction of Flow of Electricity in an Electric Circuit

PURPOSE:

To discover what difference, if any, takes place in the action of a salt solution around a conductor when the direction of flow of electricity in that conductor is changed.

MATERIALS USED:

Glass tumbler, bell wire, salt, water, two dry cells.



PROCEDURE:

Connect cells in series as shown in Exp. 10-A and fill tumbler 3/4 full of water. Drop a few grains of salt into the water.

With wire "A" connected to the positive terminal and wire "B" to the negative terminal, Exp. 10-B, carefully note the action, if any, around each of the conductors in the salt solution.

Repeat with wire "A" connected to the negative terminal and wire "B" to the positive terminal as shown in

QUESTIONS:

1. Referring to Exp. 10-A, is the action the same around each of the wires? Explain.
2. Referring to Exp. 10-B, is the action the same around each of the wires? Explain.

QUESTIONS (Continued)

3. What do you think is the reason for the difference, if any, in the action of the salt solution around the wires "A" and "B"?
4. Was the action around the wire "A" the same in both Exp. 10-A and Exp. 10-B? Was the action around wire "B" the same in both Exp. 10-A and Exp. 10-B? Explain.
5. In Experiment No. 8 we considered opposite deflections of the compass needle as proof that electricity has a direction of flow. Did anything in this experiment offer another reason for supposing that electricity has a direction of flow? Explain.
6. Give a statement, telling what fact you have discovered in this experiment.

REFERENCES:

Practical Electricity - Swoope's	Pages 46-49
Basic Electricity - Marcus	Pages 35-36
Fundamentals of Electricity - McDougal	Pages 14-16

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 11
Page 1 of 2

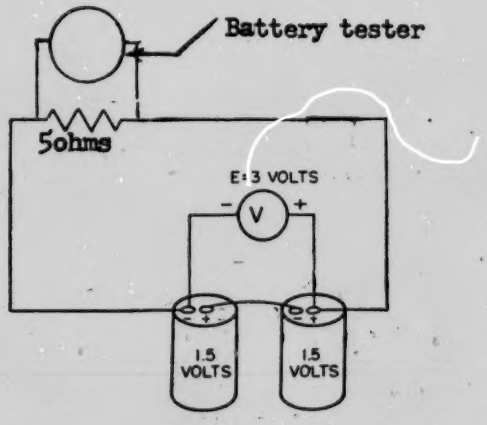
Potential Difference and Pressure

PURPOSE:

To show that there is a potential difference between two points in an electric circuit, rather than one point, as in a water system.

MATERIALS USED:

4 - No. 6 dry cells, 5 ohm resistor, battery tester and pushback wire.



PROCEDURE:

Connect 2 dry cells in series across the 5 ohm resistor. Place the battery tester across points A and B. Note meter movement.

Repeat, using 3 dry cells. Note meter reading.

Repeat, using 4 dry cells. Note meter movement.

EXPLANATORY NOTES:

The resistor is of the same value in all three experiments. We are not interested in the potential (pressure) at one point in electric current, but rather, the difference in potential (voltage) between two points. That is, just how much higher the potential is at the first point than at the second point. The difference in potential between two points is measured in volts, and is called the voltage between the points.

Experiment No. 11
Page 2 of 2

QUESTIONS

1. a. What instrument is used to measure the voltage of a circuit?

   b. How is it connected?

2. Was there any difference when the experiment was done with two cells and three cells?

3. Was the voltage across the cells the same as the voltage across the resistor? Explain.

4. If the voltage of a coil is 120 volts, does this mean that the coil has a 120 volt drop across it? Explain.

REFERENCES:

Elementary Electricity - Slack 1943 Pages 10-11

CONNECTICUT VOCATIONAL TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 12
Page 1 of 2

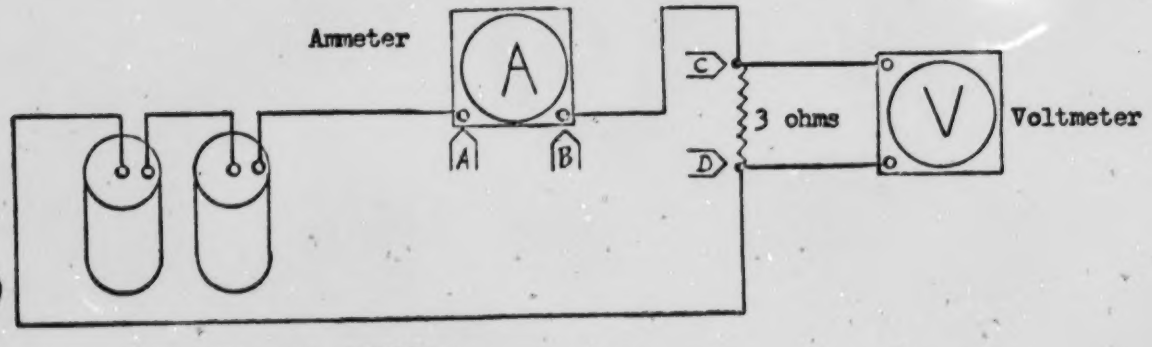
Potential Difference Varying Rate of Flow

PURPOSE:

To show that as the potential difference is increased or decreased, and other components remain constant, the rate of flow is changed.

MATERIALS USED:

4 - No. 6 dry cells, approximately 3 ohm resistor, ammeter (0-5A), and a voltmeter (0-10 V DC)



EXPLANATORY NOTES:

1. To measure the flow (current) in an electric circuit you must first open the circuit and then connect the ammeter in the gap between points "A" and "B". (Remember current has direction). If the meter deflects backwards, reverse the "A" and "B" connections.

2. To measure the pressure (voltage, E.M.F.), connect the voltmeter between points "C" and "D". With this instrument also, if the meter deflection is backwards reverse "C" and "D" connections.

Repeat, using 4 dry cells and note reading of instruments.

QUESTIONS

1. Did both meters increase or decrease in the same direction?
2. Was there any difference in the rate of flow, when using 3 cells?
3. Did the readings change in proportion, as the cells were increased?

Experiment No. 12
Page 2 of 2

QUESTIONS (Continued)

4. a. What is flow measured in?
   b. What is meant by current?
5. a. Must we break a circuit to connect an ammeter? Explain
6. Must we break a circuit to measure voltage? Explain.

REFERENCES:

Elementary Electricity - Slack 1943 Pages 9-10

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 13
Page 1 of 2

Conductors and Non-Conductors

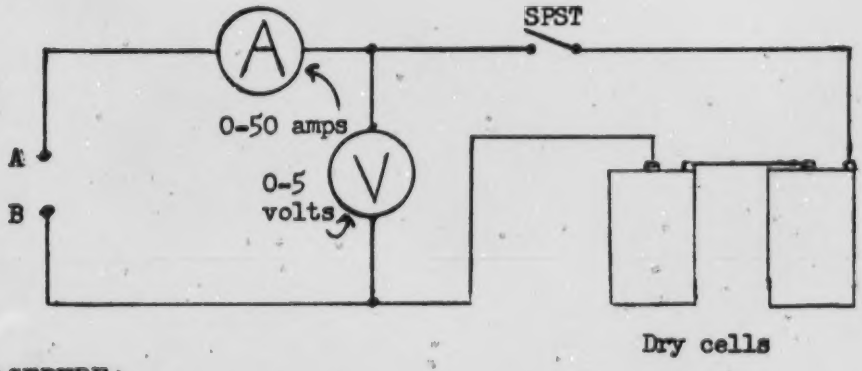
PURPOSE:

To discover which of the materials commonly used by electricians are conductors and which are non-conductors.

MATERIALS USED:

2 - No. 6 dry cells, bell wire, ammeter, voltmeter (0-5), 2 knife switch (SPST), paper, wood, rubber, bakelite, glass, cotton tape, rubber tape, friction tape, varnished cambric, copper, aluminum, iron, water, porcelain cleat, conduit, piece of B X, fish paper, solder and salt.

Sketch



PROCEDURE:

Close switch "X" and note reading of voltmeter. Now press across terminals "A" and "B" a piece of wood and note and record the action, if any, of the meters.

Adjust voltage if possible before pressing next material.

Next press the following materials in succession noting the action, if any, of the meters in each case; paper, rubber, bakelite, glass, porcelain cleat, cotton tape, rubber tape, friction tape, varnished combric, copper, aluminum, iron, fish paper, a piece of conduit, the armor on B X cable, and solder.

Connect two pieces of bell wire to terminals "A" and "B" and immerse the free ends of the wires in a tumbler of water. Note and record any action in the tumbler. Also note the position of meter movements.

PROCEDURE (Continued)

Next, add to the water a little salt, and repeat your observations.

CAUTION: DISTILLED WATER AND SOME SOFT WATERS ARE NON-CONDUCTORS, BUT IN GENERAL, WATER IS A CONDUCTOR OF ELECTRICITY. PEOPLE HAVE BEEN ELECTROCUTED BY TOUCHING FAULTY ELECTRIC LIGHT FIXTURES WHILE STANDING IN A BATHTUB.

QUESTIONS

1. Did anything in this or previous experiments lead you to believe, that "in order to have a continuous flow of electricity, it is necessary to provide a closed conducting path"? Explain.

CONNECTICUT STATE VOCATIONAL SCHOOLS
Electrical Experiments

Experiment # 14
Page 1 of 1

Completion of an Electric Circuit Through Non-Metallic Material

PURPOSE:
To show that all non-metallic materials are not insulators.

MATERIALS USED:
D.C. voltage source, 2 battery testers, push back wire, terminal board, rosin, glass, mica, carbon rods, chalk, bakelite and graphite block.

SKETCH: USE THE SKETCH FOR EXPERIMENT #13.

EXPLANATORY NOTES:
In the electrical trade, non-metallic material is needed for sliding contacts, to prevent unnecessary wearing, which causes frequent replacements.

PROCEDURE:
Press across terminals "A" and "B", one of the above materials and note the action of the testers.

Adjust voltage before pressing a different material.

Note the action of the testers after pressing different materials.

QUESTIONS:
1. Is all non-metallic material an insulator?
2. Which materials completed a circuit, permitting current flow?
3. Name several uses where the electrician needs non-metallic conductors.
4. Name several uses where the electrician needs non-metallic insulators.
5. If a bakelite panel board became charred by loose terminal posts, could it still be used as a panel board? Explain.

REFERENCES:
Direct Current Fundamentals - Loper Pages 17 - 18

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 15
Page 1 of 2

Completion of an Electrical Circuit Through the Earth

PURPOSE:

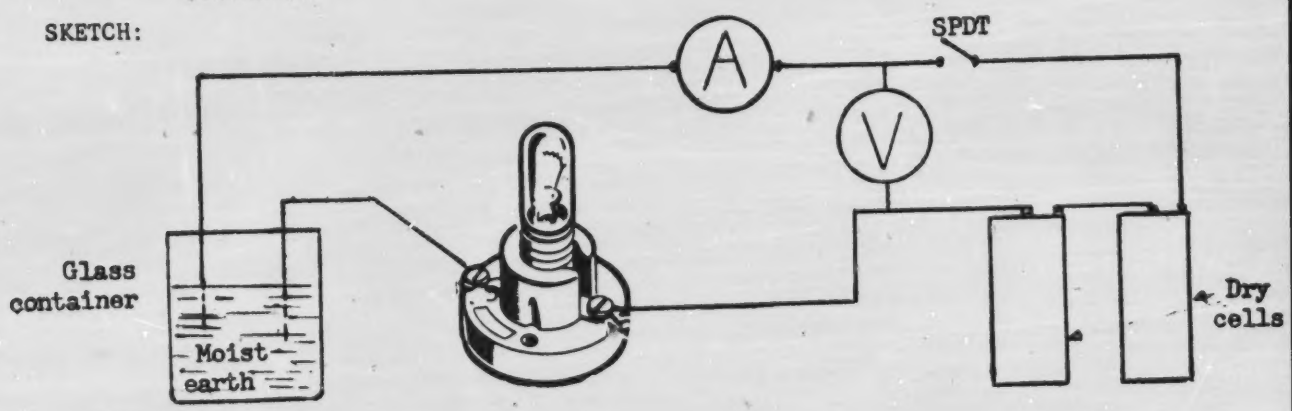
To discover whether or not the earth will serve as a portion of an electrical circuit.

MATERIALS USED:

Dry cells, moist earth, battery tester, bell wire, table salt, glass container, 3 volt lamp, knife switch.

(Note: In this experiment the optional use of separate meters is employed in place of the battery tester).

SKETCH:



PROCEDURE:

Fill the glass container with moist earth. (If the water is soft and free from minerals, it will be necessary to add a small quantity of table salt).
With the wires "A" and "B" separated and free from the container of moist earth, note the position of the needle on the meters.
Place the free end of the wire "A" into the dish of moist earth. (Have the wire "B" free from the dish).
Note the action, if any, on the meters.
With the wire "A" still in the moist earth, force the wire "B" down into the moist earth about four or five inches from wire "A". Again note the action, if any, of the needles on the meters.
Withdraw the wires "A" and "B" from the moist earth and substitute a piece of bell wire for the moist earth. With the free ends (insulation removed) of wires "A" and "B" touching this piece of bell wire, again note the action, if any, of the meters.

Experiment No. 15
Page 2 of 2

QUESTIONS:

1. (a) Is the circuit closed or open when the wires "A" and "B" are separated by air?

   (b) Is the air a conductor or non-conductor of electricity?

2. With the wires "A" and "B" separated by moist earth, what action of the needle on the tester did you notice?
3. Is the circuit closed or open? Why?
4. Is moist earth a conductor of electricity? Prove your answer.
5. What difference did you notice in the action of the needle of the tester when the piece of bell wire was substituted for the moist earth?
6. State in your own words what fact you have discovered in this experiment.
7. What use can you make of the fact you have just discovered?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 16
Page 1 of 2

Short Circuits

PURPOSE:

a. To obtain an understanding of the term short circuit.
b. To discover some of the effects, if any, produced by conductors and insulators, across a circuit.

MATERIALS USED:

Dry cell, electric door bell, push button, bell wire, nail, wood, B. X. armor, conduit, staple.

SKETCH:

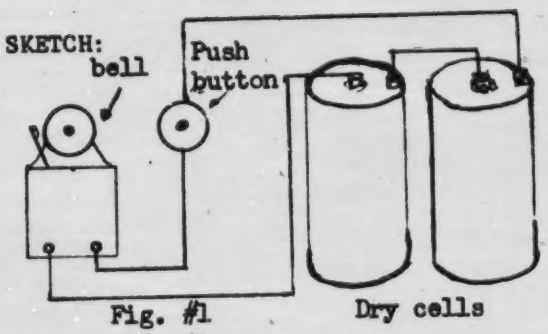


Fig. #1

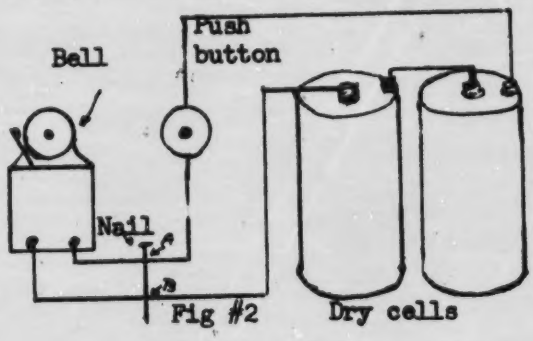


Fig #2

PROCEDURE:

Connect as shown in Fig. 1. With the wires well separated, close switch. Note the action, if any, of the bell. Open switch. Place a nail across the wires (do not remove insulation). Close switch. Note the action, if any, of the bell. Open switch.

Remove the insulation at some point such as "A". Make sure the wire is clean and bright at this point. Place a nail across the wires (Fig. 2) so that one end of the nail rests on the bare wire at "A" and the other end rests on the other wire which is covered with insulation. Close switch. Again note the action, if any, of the bell.

Open switch. Remove the nail from the wires. Next, touch the two bare spots "A" and "B" with the other material listed above and close switch. Note the action, if any, of the bell.

Next touch the two bare spots "A" and "B" (Figure 2) together. Note the action, if any, of the bell. Always close switch before testing material.

QUESTIONS

1. What is your idea of a short circuit?
2. With the wireswell separated, did the bell ring? Are the wires shorted?
3. Did placing the nail across the two wires (Fig. 2) which were well insulated, affect the operation of the circuit? Explain.
4. Did placing the nail across the two wires (Fig. 2) one of which was bare, affect the operation of the circuit? Are the wires short circuited? Explain.
5. Did placing the nail across the two wires (Fig. 2) when both were bare, affect the operation of the circuit? Are the wires short circuited? Explain.
6. Did all the material affect the bell when placed across the two bare wires?
7. Did touching the two bare wires (Fig. 2) together, affect the operation of the circuit? Are the wires shorted? Explain.
8. Give possible ways for a line to become short circuited.
9. State in your own words, what fact you have discovered in this experiment.
10. Is a short circuit a fire hazard? Explain.

REFERENCES

Elementary Electricity - Slack	Page 20
Basic Electricity - Marcus	Pages 220-261

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 17
Page 1 of 2

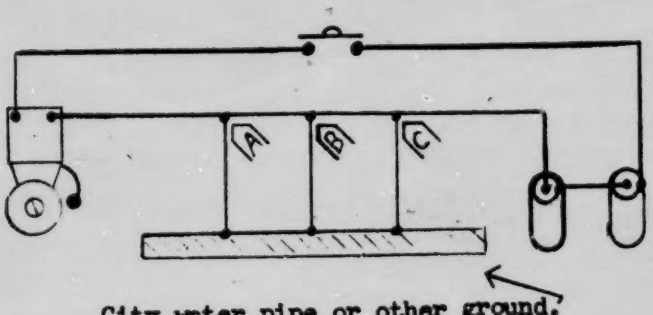
Short Circuits

PURPOSE:

To study the effects, if any, produced by two or more grounds on the same sides of a circuit.

MATERIALS USED:

Dry cell, electric door bell, bell wire and push button.



PROCEDURE:

Connect circuit as shown in Fig. 1.

Leave switch open. At any point "A" on the bell wire (Fig. 2) remove the insulation and scrape the wire clean and bright. Connect a piece of bell wire from the point "A" to a water pipe or radiator; in the words of the electrician "ground the wire". Make sure that the water pipe or radiator is clean and bright where the wire is attached. Close switch. Note action of the bell.

Repeat with a wire connected also at point "B" and note the action of the bell.

Repeat with a wire connected also at point "C" and note the action of the bell.

QUESTIONS:

1. a. Does one ground affect the operation of a circuit? Explain.
   b. Does it make any difference which side of the circuit is grounded insofar as the operation of the circuit is concerned?
2. Do two or more grounds on the same side of the circuit (Fig. 2) affect the operation of a circuit? Is the circuit shorted? Explain.

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Experiment No. 17
Page 2 of 2

QUESTIONS (Continued)

3. State in your own words what fact you have discovered in this experiment.

4. In later work you will find that at each residence one of the lighting circuit wires is grounded. So when grounding the service entering a building, why must you always be careful to ground the proper wire? (Remember what you discovered in this experiment).

5. In your B X work you will find that the white wire is always grounded. Also the armor around the cable is grounded. If the black wire accidentially becomes grounded (touches the armor of the B S, a water pipe, a gas pipe, a steel girder entering the earth, etc.), why will the fuse blow?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 18
Page 1 of 2

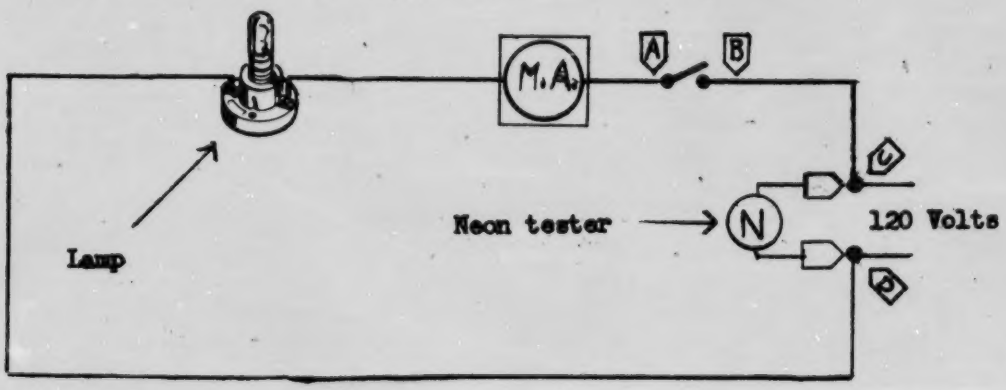
Completion of an Electric Circuit Through Gases

PURPOSE:

To show that conduction of current is possible, through a gas tube, in electrical circuits.

MATERIALS USED:

Neon lamp, neon tester, lamp receptacle, wire, voltage sources, milliammeter and SPST knife switch.



PROCEDURE:

Connect a circuit as shown in sketch with switch open. Place neon tester across terminals "C" and "D", and observe action of neon lamp when power is present.

Place neon tester across terminals "A" and "B", with switch open, and note action of the neon tester, neon lamp and milliammeter.

Repeat with switch closed and neon tester across terminals "A" and "B". Note action of the neon tester, neon lamp and milliammeter.

QUESTIONS:

1. With the knife switch open and the neon tester across "C" and "D", did the neon tester light?
2. With the knife switch open and neon tester across "A" and "B", did the neon lamp glow?
3. With the knife switch closed and neon tester across "A" and "B", did the neon tester glow?

Experiment No 18
Page 2 of 2

QUESTIONS (Continued)

4. Explain the action of the milliammeter when the neon lamp was glowing.

5. Name several uses of this principle in the home.

REFERENCES:

Direct Current Fundamentals - Loper	Pages 137-140
Practical Electricity - Swoope's	Pages 556-558

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 19
Page 1 of 2

Completion of Electric Circuits Through Vacuum

PURPOSE:

To show that it is possible to have current flow through a vacuum.

MATERIALS USED:

2 element vacuum tube, battery supply, tube socket, galvanometer, and push back wire.

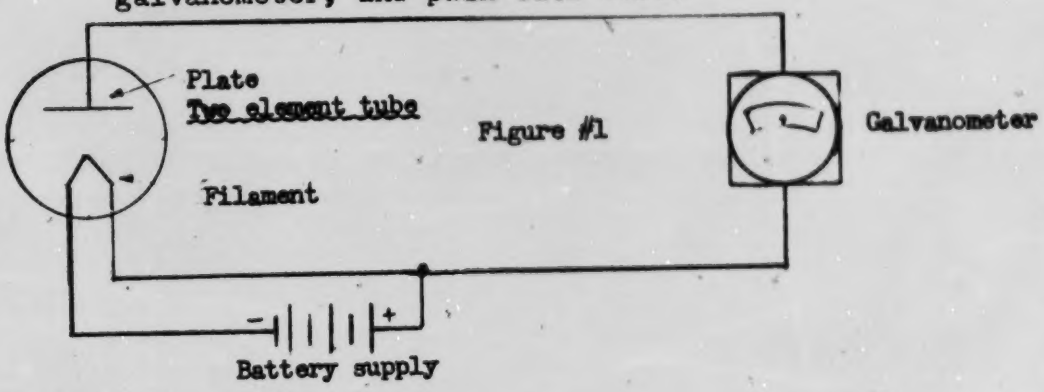


Figure #1

PROCEDURE:

Carefully study the construction of the vacuum tube assigned. Referring to Fig. 1, F is the filament and P the plate.

Apply rated D.C. voltage to the filament. Allow the filament to heat up.

Connect a sensitive galvanometer from the plate to the positive terminal of the filament as shown in Fig. 1. Note whether or not the galvanometer deflects. If it deflects, note the direction of deflection.

Repeat the experiment with the battery, Fig. 1 reversed. Note the direction of deflection.

Repeat the experiment with the galvanometer connected between the plate and the negative terminal of the filament.

Experiment No. 19
Page 2 of 2

QUESTIONS:

1. Describe fully what you observed while performing experiment.
2. Does the plate current (the current shown by the galvanometer in Fig. 1) always flow in a definite direction regardless of which direction the current may be flowing in the filament? Explain.
3. When an electric current passes through the filament, it is heated to a red heat. This causes the filament to shoot off electrons (Particles of negative electricity) into the space surrounding it. This is the working principle of thermionic vacuum tubes. Explain how this experiment illustrates the fundamental prindple of operation of a vacuum tube.
4. Explain how the two-element tube acts as a rectifier permitting the current to flow in one direction only.

REFERENCES:

Practical Electricity - Swoope's	Pages 585-588
Elementary Electricity - Slack	Pages 252-253
Direct Current Fundamentals - Loper	Pages 140-142

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 20
Page 1 of 2

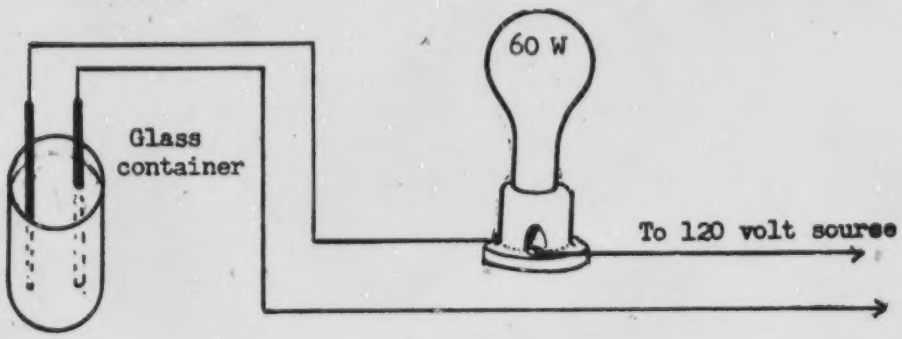
Completion of Electric Circuits Through Liquids

PURPOSE:

To show that materials, dissolved in water, conduct current flow in an electrical circuit.

MATERIALS USED:

Power source, 60 watt lamp, lamp receptacle, glass container, kerosene, water, table salt and connecting wire.



EXPLANATORY NOTES:

Common liquids, such as oils, alcohols and solvents are classed as insulators rather than conductors. However, water dissolves a good many materials which give the solution the ability to conduct. In general, the other liquids do not become conducting when substances are dissolved in them. It is the purpose of this unit to explain the behavior of these water-dissolved materials, understanding of which is essential to explanation of the operation of batteries and other chemical processes, making use of electric current through water solutions.

PROCEDURES:

Connect lamp to one side of power supply and extend the other side of lamp and power supply to the glass container, as shown in the sketch.

Pour kerosene into the glass container and immerse the "A" and "B" leads in the solution. Observe the lamp.

Experiment No. 20
Page 2 of 2

PROCEDURES (Contimued)

Replace kerosene with water and immerse "A" and "B" leads into the container. Observe the lamp.

Repeat with salt added to the water. Observe the lamp.

QUESTIONS:

1. Is kerosene a conductor of electricity?
2. When the salt was added to the kerosene, was there current flow?
3. When salt was added to the water solution, did the lamp get brighter? Explain.
4. What fact did you discover in this experiment?
5. Can solids be mixed with liquids so as to change them from insulators to conductors? Explain.

REFERENCES:

Direct Current Fundamentals - Loper	Pages 129-135
Practical Electricity - Swoope's	Pages 90-94
Elementary Electricity - Slack	Pages 33-35

Experiment No. 21
Page 1 of 2

Completion of an Electric Circuit Through Gases

PURPOSE:

To show that conduction of current is possible, through a gas tube, in electrical circuits.

MATERIALS USED:

Neon lamp, neon tester, lamp receptacle, wire, voltage source, voltage tester and SPST knife switch.

PROCEDURE:

Connect a circuit as shown in sketch, with switch open. Place neon tester across terminals "C" and "D", and observe action of neon lamp when power is present.

Place neon tester across terminal "A" and "B", with switch open and note action of the neon tester, neon lamp, and voltage tester.

Repeat with switch closed and neon tester across terminals "A" and "B". Note action of the neon tester, neon lamp and battery tester.

QUESTIONS:

1. With the knife switch open and the neon tester across "C" and "D", did the neon tester light?
2. With the knife switch open and neon tester across "A" and "B", did the neon lamp glow?
3. With the knife switch closed and neon tester across "A" and "B", did the neon tester glow?
4. Explain the action of the voltage tester when the neon lamp was glowing.
5. Name several uses of this principle in the home.

Experiment No. 21
Page 2 of 2

REFERENCES:

Direct Current Fundamentals - Loper	Pages 137-140
Practical Electricity - Swoope's	Pages 556-558

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 22
Page 1 of 2

The Thermo-Electric Principle

PURPOSE:

To discover what happens, if anything, when heat is applied at the junction of two dissimilar metals (the other end remaining at room temperature).

MATERIALS USED:

#18 P.E. copper wire, #18 iron wire, galvanometer, alcohol torch.

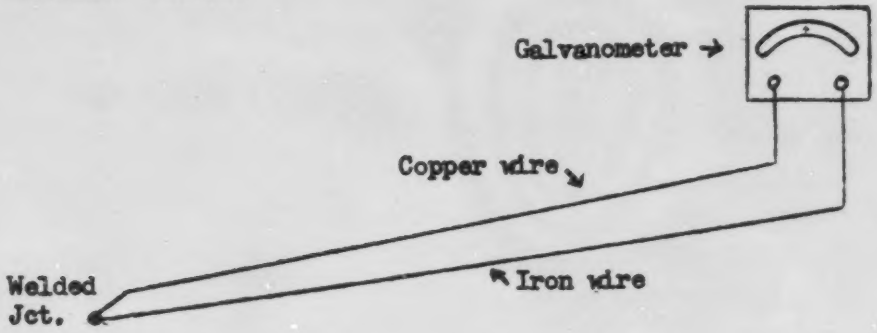


Fig. 1

PROCEDURE:

Tightly twist together (weld if possible) a piece of #18 copper wire about 3 feet long and a piece of #18 iron wire of about the same length. Connect a galvanometer across the free ends as shown in Fig. 1. (Have the wires between the junction and galvanometer insulated from each other.) Note the position of the galvanometer needle.

Apply heat at the junction of the wires. Be sure that the heat is applied only at the junction because it is essential that the free ends of the galvanometer remain at room temperature. Carefully watch the needle of the galvanometer as the junction becomes warmer. Continue heating the junction until red hot. Allow the junction to slowly cool, watching the needle of the galvanometer all the while.

QUESTIONS:

1. Explain in detail what you observed to take place in this experiment.
2. Was the action, if any, more or less as the junction became hotter? Explain.
3. Name all the methods with which you are familiar for producing an e.m.f.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 23
Page 1 of 2

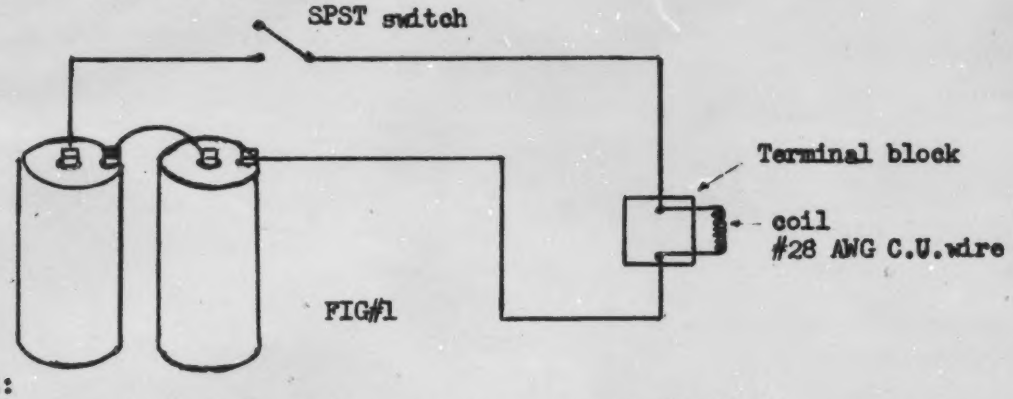
Heating Effect Produced by Electricity Flowing in a Circuit

PURPOSE:

To discover whether or not there is any change in the temperature of a conductor when electricity is sent through it.

MATERIALS USED:

D C voltage source, #28 AWG copper wire, terminal post stand, #14 AWG copper wire for leads, SPST knife switch, thermometer.



FIG#1

PROCEDURE:

Take a piece of #28 AWG copper wire about 3½ feet long and wind it around a pencil. Remove the coil from the pencil and connect the free ends of the coil to the binding post. (See Fig. 1). Complete the wiring using #14 AWG copper wire, as shown in Fig. 1. Leaving the switch open, insert thermometer into the coil and read temperature. Close switch and again read temperature.

Repeat experiment using "Sense of Touch". (Exercise extreme care as the heat in some instances is sufficient to cause a burn). Not the change, if any, in the feeling of the wire. Also note the change, if any, in the appearance of the wire.

QUESTIONS:

1. What change, if any, did you note in the reading of the thermometer with the switch open and the switch closed?

Experiment No. 23
Page 2 of 2

QUESTIONS (Continued)

2. What change, if any, did you note in the appearance of the wire when the switch was closed allowing electricity to flow?
3. When the "Sense of Touch" was used, how did the coil feel when electricity was flowing in it?
4. What do you think caused the action you noted in performing this experiment?
5. Why is it important that every electrician have knowledge of the fact you have just discovered?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 24
Page 1 of 2

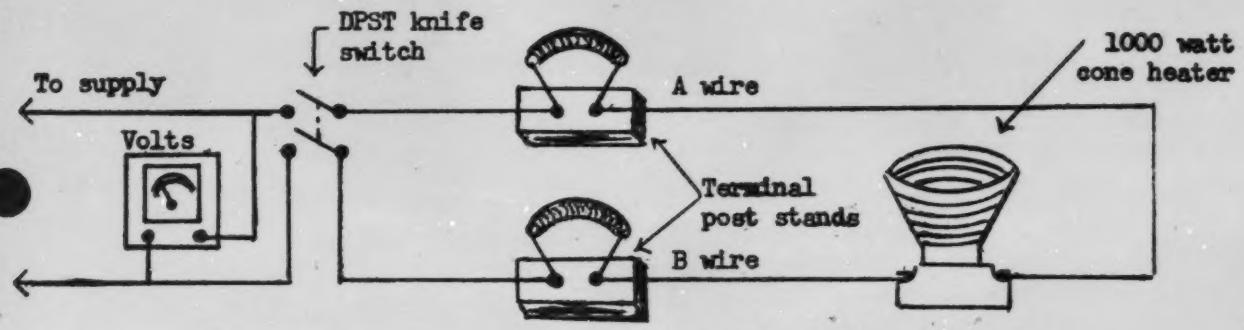
Comparison of Heating Effects of Electric Current in Conductors of Different Sizes

PURPOSE:

To discover whether or not the Size (cross sectional area) of a conductor, has any effect upon the temperature of the conductor carrying electricity.

MATERIALS USED:

Power supply, #14 AWG copper wire, #18 AWG copper wire, #20 AWG copper wire, #22 AWG copper wire, #24 AWG copper wire, #28 AWG copper wire, lamp receptacle, 1000 watt cone heating element, thermometer, DPST knife switch, voltmeter, 2-terminal post stand.



PROCEDURE:

Connect switch, test stands, and lamp receptacle as shown in sketch. A and B wires should be regular lead wire.

Take a piece of #12 AWG copper wire about 2 feet long and wind it around a pencil. Remove coil from around pencil and connect across test stand #2.

Take a piece of #14 AWG copper wire and wind around a pencil. Remove from pencil and connect across test stand #1.

Insert cone heater and adjust voltage to the value that the instructor recommends.

Insert thermometer in #2 coil and note temperature. Close switch and again note temperature. Open switch.

Experiment No. 24
Page 2 of 2

PROCEDURE (Continued)

Insert thermometer in #1 coil and note temperature. Close switch and again note temperature. Open switch.

NOTE: Always open switch before replacing #1 coil with a different size wire.

Coil the different size wires on a pencil and substitute for coil on test stand #1 until each coil has been tested. Always note temperature before closing switch and again after closing switch.

QUESTIONS:

1. With both coils #14 AWG, how did the temperature of the two wires compare?
2. With #1 coil #18 and #2 coil remaining the same, how did the temperature of the two wires compare?
3. With #1 coil #20, and #2 coil remaining #14, how did the temperature of the two wires compare? Explain.
4. Compare the temperature of #22 with 14.
   Compare the temperature of #24 with 14.
   Compare the temperature of #28 with 14.
5. Both coils #1 and #2 carry the same current. For a given current does the size of wire have any influence upon the amount of heat produced? Explain.
6. Does increasing the size of the wire increase or decrease the amount of heat produced? Does decreasing the size of the wire, increase or decrease the amount of heat produced?
7. Did the appearance of the wire change when electricity was flowing in it? Explain.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
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Experiment No. 25
Page 1 of 2

Comparison of Heating Effects of Electric Current in Conductors of Different Materials

PURPOSE:

To discover whether or not the kind of material used as a conductor has any effect upon the amount of heat produced in a conductor carrying electricity.

MATERIALS USED:

DPST knife switch, terminal post stand, lamp receptacle, 1000 watt cone heater, thermometer, power supply, voltmeter, #18 AWG copper wire, #18AWG iron wire, #18 AWG aluminum wire, #18 AWG manganin wire, lead wires for connections.

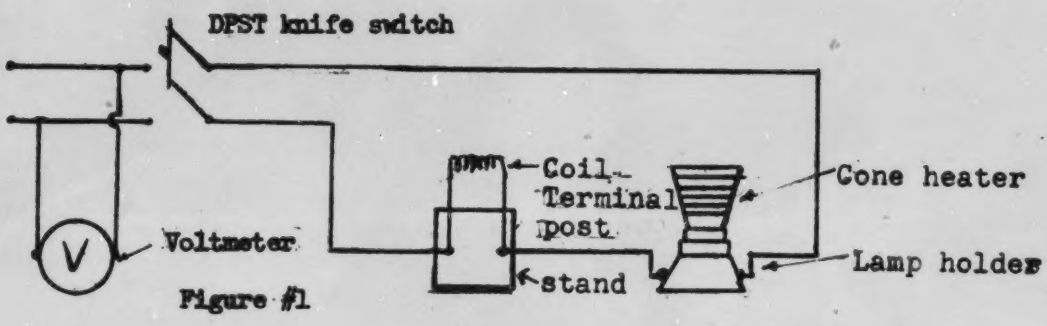


Figure #1

PROCEDURE:

Connect circuit as shown in Fig. 1 with connecting wires, leaving switch open.

Using a pencil make a coil by wrapping 2 feet of #18 AWG copper wire around the pencil. Remove coil and insert in the terminals of the test stand. Insert the cone heater, adjust voltage to the value recommended by your instructor.

Insert thermometer into the coil under test, and note reading. Close switch and again note reading.

NOTE: Leave each wire in the circuit for about 10 minutes after closing switch, for best reading.

Repeat experiment by substituting coil under test with the various materials furnished, noting temperatures, both before and after closing the switch. Note how the temperature varies in the different coils under test.

Experiment No. 25
Page 2 of 2

QUESTIONS:

1. How did the temperature of the iron wire compare with that of the copper wire?
2. How did the temperature of the aluminum wire compare with that of the manganin wire?
3. With the same size wire, the same length of wire, and the same current, how did the temperature of copper, iron, aluminum and manganin wire compare? Explain by telling which is the hottest and the one which is coolest.
4. Does the kind of material used as a conductor have any influence upon the amount of heat produced? Explain.
5. List the order for the following:

Post Conductor	Greatest Amount of Heat
1.	1.
2.	2.
3.	3.
4.	4.

6. Why should every electrician know the fact you have just discovered?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 26
Page 1 of 2

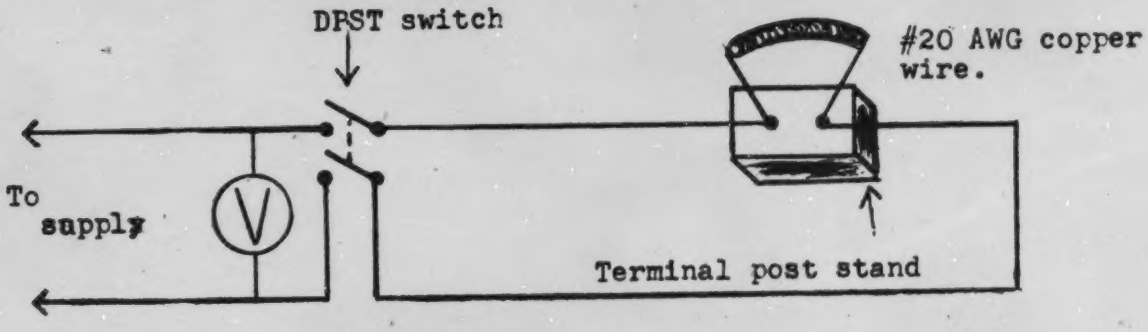
Comparison of Heating Effects Using Different Time Intervals

PURPOSE:

To discover whether or not more heat is produced in a conductor by increasing the length of time the electricity flows.

MATERIALS USED:

Power source, DPST knife switch, terminal post stand, voltmeter, thermometer, #20 AWG copper wire, connection wire.



PROCEDURE:

Take a piece of #20 AWG copper wire about 3 feet long. Wind the wire around a pencil. Remove the coil and connect the free ends to the terminal stand. Connect the other equipment as shown in Fig. 1, with regular wire.

With switch open, adjust the voltage to the value recommended by the instructor.

Insert thermometer into the coil and note reading, close switch, again note reading.

After 15 seconds again read the thermometer and cautiously feel the wire, note change, if any.

After 60 seconds again read thermometer and cautiously feel the wire, again note change, if any.

Note what change, if any, there is in the appearance of the wire after 1 second, 5 seconds, 30 seconds, 60 seconds. Explain.

Experiment No. 26
Page 2 of 2

QUESTIONS:

1. Was the feeling and appearance of the wire the same or different after 1 second, 15 seconds, 30 seconds, 60 seconds? Explain.
2. Does time in any way enter into the amount of heat produced by electricity flowing through a wire? Explain.
3. If an electric flatiron is not provided with an automatic device for opening the circuit when the iron reaches a definite temperature, what do you think would happen if such an iron was left in the circuit for several hours? Explain.
4. State in your own words what facts you have discovered in this experiment.
5. Of what value is this fact to the electrical industry, and to you as an electrician?

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Electrical Experiments

Experiment No. 27
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Comparison of Heating Effect Using Different Amounts of Current

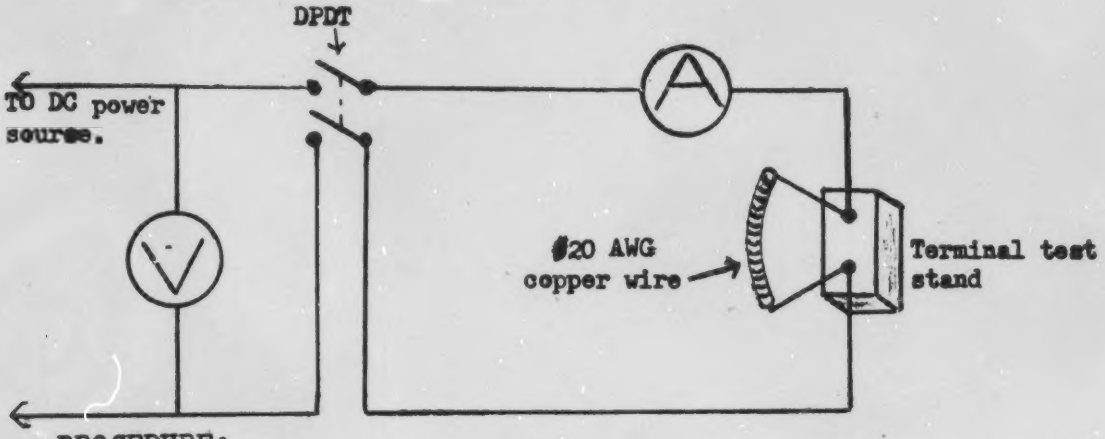
PURPOSE:

To discover whether or not there is any difference in the temperature of a wire when different amounts of current are sent through it.

Definition - Current is the amount of electricity flowing through a circuit in a given time.

MATERIALS USED:

D C power source, DPST knife switch, terminal test stand, connection wire, #20 AWG copper wire, voltmeter, ammeter, thermometer.



PROCEDURE:

Take a piece of #20 AWG copper wire about 2 feet long and wrap it around a pencil, remove coil and insert it on the test stand.

Connect voltmeter across the line. Connect ammeter in the line (Fig. 1). Leave switch open.

Adjust voltage to value recommended by the instructor.

Insert thermometer into coil. Close switch. Allow about 5 minutes for coil to heat.

Read thermometer and cautiously feel coil. Note change, if any, in the temperature and appearance of the wire. Open switch.

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QUESTIONS:

1. What difference, if any, did you notice on the thermometer when the voltage was doubled.
2. Was there any difference on the ammeter reading during the two experiments. Explain.
3. Does increasing the voltage, without changing the wire, increase or decrease the current?
4. Rubber covered #14 AWG copper wire can safely carry 15 amperes. Explain what you think would happen if the wire had 50 amperes sent through it for any length of time.
5. What uses can you make of the fact that you have discovered in this experiment?

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Electrical Experiments

Experiment No. 28
Page 1 of 2

Comparison of Heating Effects of Electic Current in Conductors of Different Lengths

PURPOSE:

To discover whether or not the length of a conductor has any effect upon the amount of heat produced in a conductor carrying current.

MATERIALS USED:

DPST knife switch, terminal test stand, lamp receptacle, 1000 watt cone heater, #20 AWG copper wire, voltmeter, connection wire, D C power source.

SKETCH:

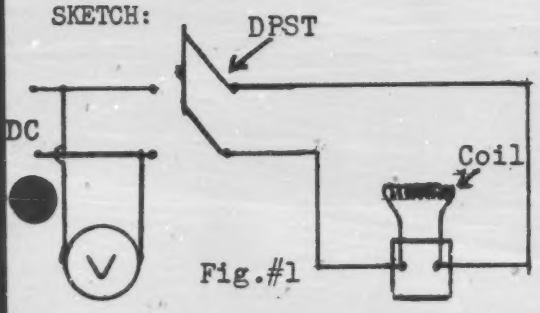

Fig.#1

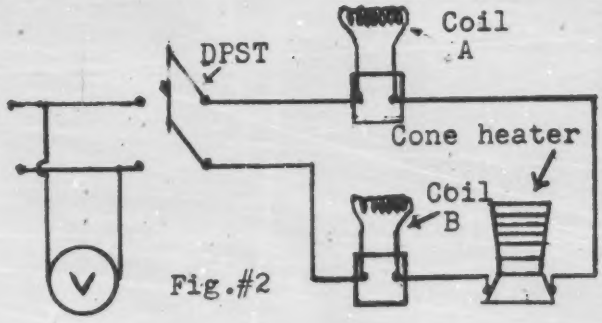

Fig.#2

PROCEDURE:

Part 1:

Current decreases as the length of the wire increases. Make a coil by winding 2 feet of #20 AWG copper wire around a pencil. Remove coil and connect to test stand. Connect material as shown in Fig. 1, leaving switch open. Adjust voltage to value recommended by the instructor.

Insert thermometer into the coil, close switch, after 30 seconds read thermometer. Cautiously feel coil and note temperature and appearance of wire. Open switch, remove coil.

Take a piece of #20 AWG copper wire about 20 feet long and make a coil as before. Connect new coil to test stand. Insert thermometer into coil, close switch. After 30 seconds read thermometer. Cautiously feel coil and note change, if any, in the temperature and appearance of wire.

PROCEDURE (Continued)

Part 2:

Current remains constant.
Connect 1000 watt cone heater in circuit replacing test stand (Fig. 2).

Wind a coil with 5 turns of #20 AWG copper wire around a pencil. Apply a layer of friction tape. Remove from pencil and replace A lead (Fig. 2). Wind another coil with about 100 turns (using same size and kind of wire). Apply a layer of friction tape. Remove from pencil and replace B lead (Fig. 2).

Adjust voltage to value recommended by the instructor.

Insert thermometer in A coil, close switch. After 5 minutes read thermometer, cautiously feel coil. Note change, if any, in the temperature and appearance of wire. Open switch.

Insert thermometer in B coil, close switch. After 5 minutes read thermometer, cautiously feel coil. Note change, if any, in temperature and appearance of wire. Open switch.

Uncoil and straighten out the wire in each of the coils. (leave the wire connected in the circuit). Close switch. After 5 minutes cautiously feel wire. Note change, if any, in the temperature and appearance of the wires.

QUESTIONS:

1. In Part 1 was the wire hotter, cooler, or did it remain at the same temperature, as its length was increased? Explain.
2. In Part 2, was the wire hotter, cooler, or did it remain at the same temperture as its length was increased? Explain.
3. Was the thermometer reading different for the A coil, in respect to the B coil? If so, explain.
4. When the B coil was straightened out, did the temperature increase or decrease?
5. List all things (factors) upon which the heating effect of an electric current depends.
6. Explain how each of the factors, which you have already listed, influence the heating effect of an electric current.

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Electrical Experiments

Experiment No. 29
Page 1 of 2

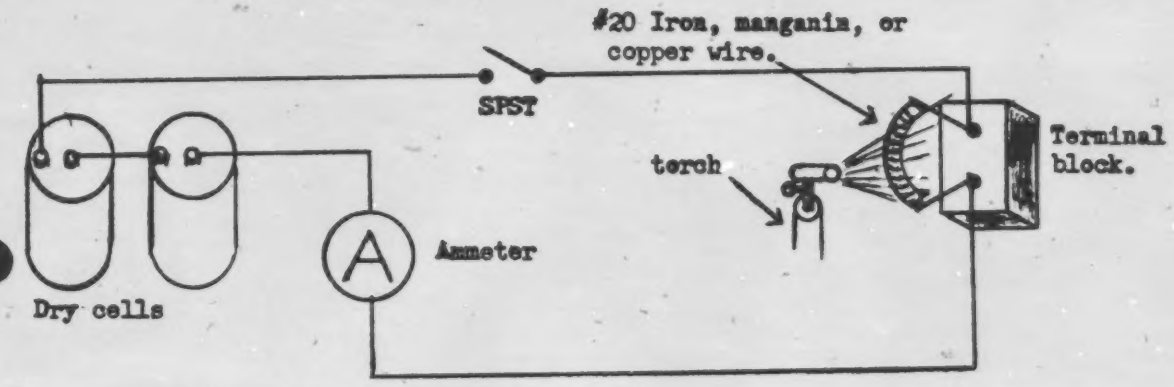
Effects of Temperature Upon the Resistance of a Wire

PURPOSE:

To study the effect, if any, of heat upon the resistance of a wire.

MATERIALS USED:

SPST knife switch, ammeter, torch, 2 - dry cells, #20 PE copper wire, #20 iron wire, #20 manganin wire.



PROCEDURE:

Wind about 45 turns of #20 PE copper wire around a pencil. Connect this coil into circuit as shown in sketch.

Close switch. Note reading on ammeter. Light torch and cautiously heat wire. Note change, if any, in the battery tester. Turn off torch. Open switch.

Repeat experiment using a coil with 45 turns of #20 manganin wire.

EXPLANATORY NOTE:

The resistance of most metals increases as their temperaturs increase. However, the resistance of some materials, decreases as they are heated. Moreover, the resistance of certain alloys such as manganin and nickel alloy, change but little as heated.

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QUESTIONS:

1. What effect, if any, does heat have upon the resistance of a conductor?
2. What difference, if any, did the ammeter show, between the copper wire and the iron wire, when the wires were heated?
3. Before heating the wires, did the ammeter show a difference in the reading, for copper wire and the manganin wire?
4. List the order in which the heat affected the current flow the greatest amount, in the various coils.
5. If a lamp was substituted in place of the ammeter would it glow brighter or dimmer when the coils are heated? Explain.

REFERNCES:

Elementary Electricity - Slack	Page 55
Practical Electricity - Swoope's	Pages 117-120

CONNECTICUT VOCATIONAL TECHNICAL SCHOOLS
Electrical Class

Electrical Development of Heat

EXPLANATORY NOTE:

Power wasted in Heating Conductors:

In your experiments you have discovered that heat is always produced in a wire when electricity flows through it. Although the electrical development of heat has many valuable commercial applications, as was pointed out to you in this lesson, nevertheless, in many cases, this production of heat often results in waste and sometimes creates a fire hazard. Every conductor carrying electricity produces heat but, under normal conditions, a conductor (wire) does not and should not even feel warm. The reason for this is that the heat produced is radiated to the surrounding air as fast as it is produced, if the conductor is the proper size. This heat represents a loss, and as you will find later, it must be given careful consideration, especially in long transmission lines, etc. Similarly, the heat produced in a motor, generator, etc. and even the heat given off by the electric light bulb, represents a waste. It is evident, therefore, that whenever electricity passes through any conductor a certain amount of electrical energy is transformed into heat energy which is sometimes used and other times wasted.

The allowable or safe carrying capacities of conductors (wires) given in the National Electrical Code (N.E.C.) are determined by the currents which these conductors will carry continuously without injury to their insulations or material near them. Overloaded wires cause fires.

FUSES:

In the experiments you discovered that, if you passed too much current through a wire, that wire became hot and the insulation took fire. Thus, it is evident that we must have an "electrical safety valve" to protect wiring systems from overloads and short circuits. One device used for this purpose is a fuse, the essential part of which is a strip of fusible alloy consisting of tin and lead. The fuse is inserted in the circuit, and its operation depends on the heating effect of the current. The alloy, having a lower melting point than the wire of the circuit, melts when an overload or a short circuit occurs and thereby opens the circuit before any damage can be done.

HOUSEHOLD APPLIANCES:

So far in this lesson we have considered the heating effect of an electric current as wasteful. However, all electrical appliances such as flatirons, waffle irons, toasters, coffee percolators,

electric egg boilers, curling irons, electric tea kettles, table stoves and hot plates, electric corn poppers, electric doughnut bakers, egg cookers, heating pads, electrical ranges, heaters, water heaters, coffee urns, frying griddles, soldering irons, glue pots, etc., utilize the heating effect of an electric current. The heating element in these may be iron wire, nichrome wire (an alloy of nickel and chromium) etc. Nichrome and similar alloys are much superior to iron wire because they will better withstand oxidation.

ELECTRIC FURNACES:

An important industrial application of heating effect of an electric current is its uses in electric furnaces. There are three general types of electric furnaces: (1) those where the electricity is passed directly through heating elements, (2) Arc-type furnaces where the heat is produced by an electric arc. (3) Induction furnaces which you will study later. A few of the many uses for electric furnaces are making carborundum, graphite, etc., melting, annealing, hardening, and heat treatment of steels, making steel, japanning, baking, enameling, etc.

INCANDESCENT LAMPS:

The production of light in an incandescent lamp depends upon the heating effect of an electric current. The light is produced by heating a conductor (called a filament) to a state of incandescence (white heat) by passing an electric current through it. To prevent it from burning up, the filament (tungsten) is sealed in a vacuum or in an inert gas within a glass bulb.

QUESTIONS:

1. (a) What would happen if a circuit were not protected by fuses or circuit breakers and a short circuit occurred on the system?
   (b) Why is it dangerous to place a penny under a plug fuse?
2. (a) What is a fuse?
   (b) How does it work?
3. Consult reference books.
   (a) Describe the construction of a cartridge fuse.
   (b) Describe the construction of a plug fuse.
   (c) May plug fuses be used on a 230 volt circuit? (See N.E.C.)
   (d) Why are fuses commonly inclosed in an asbestos tube as in the cartridge fuses, or in a procelain cup which screws into a socket as in the plug fuse?
4. Explain how advantage is taken of the heating effect of an electric current in the construction of electric heaters and similar appliances.
5. What is an electric furnace? Name some of its uses.

6. (a) What are the requirements of the National Electric Code with regard to making splices?

   (b) Why are these requirements made?

7. On a certain installation two cables were joined together by soldering a lug to each cable and then bolting the two lugs together. If the electrician had been careless and left the bolts rather loose, what would have happened?

8. Explain how an incandescent lamp produces light?

9. (a) Cite examples where the heating effect of electricity represents a loss.

   (b) Of what value to an electrician is this information?

10. If a cartridge fuse does not fit snugly into the fuse clips of the cut-out, premature blowing of the fuse results. Why?

REFERENCE:

Swoope's - Lesson in Practical Electricity	Pages 189-190
Slack - Elementary Electricity	Pages 28-31

Concepts of Volt, Ampere, and Ohm

EXPLANATORY NOTE:

The exact nature of electricity is not known. But, as you have already discovered, the flow of electricity through a circuit resembles in many ways the flow of water through pipes. However, you must bear in mind that the comparison is merely for convenience. Electricity is not a fluid like water. Electricity does not have volume or weight while water does. We can see, taste, small, and touch water, and hear it flowing through a pipe, but this is not true of electricity. The only way we may recognize electricity is by the various effects it produces. Therefore, you must remember that when we are comparing water and electricity, we are not explaining the nature of electricity. All we are doing is comparing the laws governing the flow of water. The only reason for making these comparisons is to be able to more easily understand the Laws of Electricity.

QUANTITY:

Gallon and Coulomb.

The quantity of water flowing through a pipe might be stated as a certain number of gallons. Similarly, the quantity of electricity flowing along a conductor is expressed as a certain number of coulombs. Coulomb is the unit of quantity of electricity just as the gallon is a unit for quantity of water.

CURRENT:

Gallon per second and Ampere (coulomb per second).

In previous experiments, we have not emphasized the distinction between an electric current and electricity. But, strictly speaking the word "current" has a very special and definite meaning. Electric current means the rate at which the electricity is flowing. There is no electric current until there is a flow of electricity.

Let us compare the two different units vis, quantity and current, both for a water system and an electric circuit. Suppose for example the quantity of water passing through a pipe is 50 gallons. This is simply the quantity of water and does not tell how fast the water is flowing. Suppose it takes 5 seconds for this water to flow past some point. Then there would be 50 divided by 5 equals 10 gallons flowing past that point every second. We would, therefore, say that the current (rate of flow) is 10 gallons per second. Imagine that the quantity of electricity flowing along a conductor is 50 coulombs. Similarly, as in the case of the water

system, it does not tell how fast the electricity is flowing. Suppose it takes 5 seconds for this electricity to flow past some point. Then there would be 50 divided by 5 equals 10 coulombs flowing past that point every second.

This rate of flow is called an electric current.

For the example given, we might say, that the current (rate of flow) is 10 coulombs per second. Although this is entirely correct, it is shorter to call it 10 amperes. An ampere (the unit for electric current) is one coulomb per second.

EXPLANATORY NOTES (Continued)

In our study of electrical machinery we shall almost wlways be interested in electricity in motion, (current) because electricity at rest (static electricity) has a few effects of practical value. Therefore, we shall not be studying quantities of electricity but rather currents of electricity and shall constantly use the term ampere and rarely the term coulomb.

RESISTANCE: Ohm.

Again the electric circuit is similar to the water system. As the walls of the pipes offer an opposition (due to friction) to the flow of water through them, similarly, the conductors offer resistance to the flow of electricity through them. In the water system we have no unit for resistance, but the unit for electrical resistance is the OHM. By definition one ohm is equal to the resistance of a coulomb of pure mercury 106.3 centimeters long whichhas a uniform cross section of one square millimeter; the temperature being that of melting ice (0°C). The definition need not be memorized. It is given to show that there is a standard resistance by which the resistance of all other conductors may be compared.

Resistance is the opposition which regulates the flow of electricity. The unit of resistance is the ohm.

PRESSURE AND POTENTIAL:

Electromotive Force, Voltage.

You have already discovered that to have electricity flow along a conductor, we must have an electromotive force just as we have a driving or motive force (furnished by a pump or gravity) to cause water to flow along a pipe. In a water system this motive force is expressed in pounds per square inch, or "feet of head." In the electric circuit it is expressed in VOLTS.

Volt is the unit of electromotive force. A volt may be defined as the electromotive force needed to drive a current of the ampere through a resistance of one ohm.

The terms "electromotive force," "voltage", difference of potential, and "potential" all refer to the moving force which causes force refers to the total force applied to the entire circuit. Whereas voltage, difference of potential, or potential may refer to the force applied to only parts of the circuit.

ELECTRICAL TERMS AND THEIR CONCEPTION:

(a) CURRENT (rate at which electricity is flowing)
(b) VOLTAGE (moving force which causes current to flow)
(c) RESISTANCE (opposition which regulates the flow)
(d) AMPERE (unit of current)
(e) VOLT (unit of electromotive force)
(f) OHM (unit of resistance)

CONNECTICUT VOCATIONAL TECHNICAL SCHOOLS
Electrical Class

Homework Assignment - Hydraulic Analogy

Concept of Volt, Ampere, and Ohm

REFERENCE MATERIAL:

Slack - Elementary Electricity - 1943	Pages 1-8
Fundamentals of Electricity - McDougal	Pages 19-23
Direct Current Fundamentals - Loper	Pages 10-15

QUESTIONS:

1. Do we know the exact nature of electricity? Explain.
2. List all the effects, which you have discovered in previous experiments, that an electric current produces.
3. What is the distinction between electricity and current? Coulomb and Ampere?
4. What is the unit of electric current?
5. What is voltage?
6. What is the unit for electromotive force, voltage, potential difference, difference of potential?
7. Can potential exist without a current flowing? Explain.
8. What is resistance?
9. What is the unit of resistance?
10. Who was Alexandro Volta? Andre Marie Ampere? Dr. George S. Ohm? Where did the term volt, ampere, and ohm come from?
11. Name something in an electric circuit that corresponds to the following items in a system of water piping:

    Pump
    Coil of pipe
    Valve
    Discharge pipe of pump
    Rate of flow of water
    Friction of pipe

12. Why must every electrician have a clear idea of a volt, an ampere and an ohm?
13. From your observations in previous experiments, give reasons for assuming that an electric current has a direction of flow.
14. What is the distinction between volts, amperes, and ohms?

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Experiment No. 30
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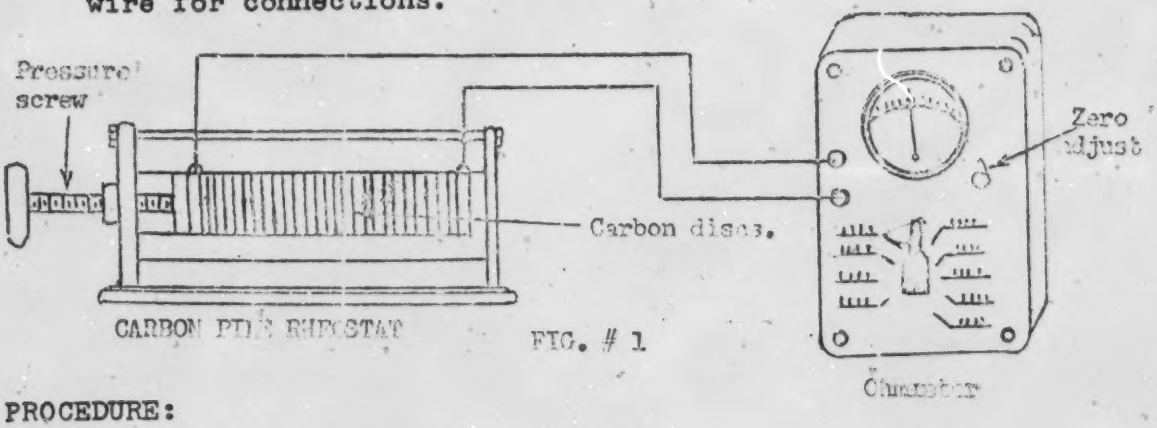
Change of Resistance with Change of Mechanic Pressure

PURPOSE:

To show that a change of mechanical pressure can cause a change in resistance.

MATERIALS USED:

Carbon pile compression rheostat (Cenco #82900, or Welch 2748H, or similar) a low range ohmmeter (0-50 ohms), a lamp bank (4 to 8 sockets), 4-100 watt lamps or 8-50 watt lamps, a source of power supply (115 volts), a voltmeter (0-150 v), and miscellaneous wire for connections.



CARBON PILE RHEOSTAT FIG. # 1

PROCEDURE:

Part 1

(a) Connect up the rheostat and ohmmeter as shown in Fig. 1. (Note) Always check the ohmmeter for zero setting and adjust if not correct.

(b) With the pressure screw in its out or loose position check the high resistance valve on the ohmmeter.

(c) Gradually screw in (tighten) on the pressure screw observe over the entire range the readings on the ohmmeter. (Caution) When the carbon disc are at their tightest compression valve do not put excessive pressure on, as this may crack the discs.

(d) Gradually unscrew (loosen) the pressure and note the readings on the ohmmeter.

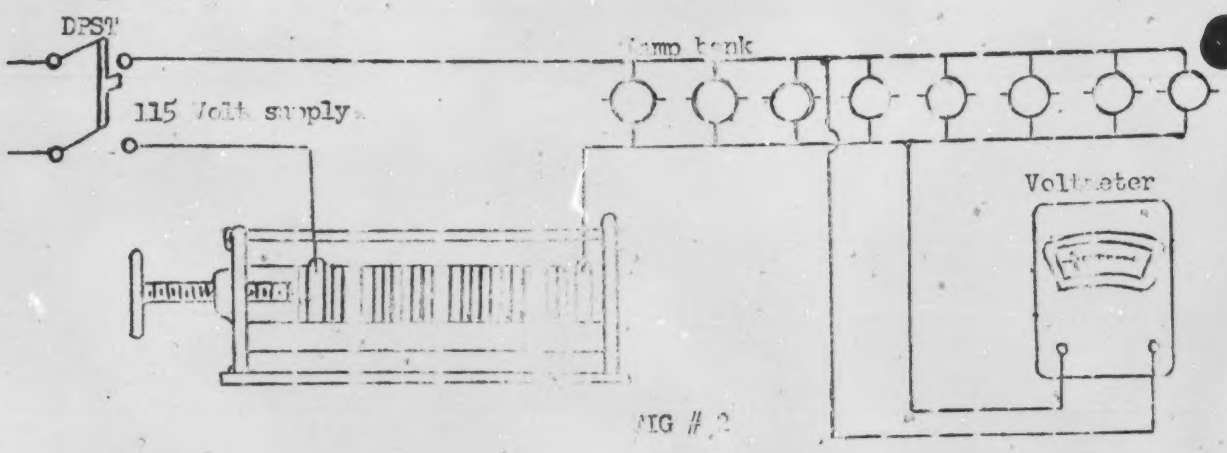


FIG # 2

PROCEDURE:

Part 2.

(a) Connect up the equipment shown in Fig. 2. Install 4-100 watt lamps (or 8-50 watt lamps, or any combination of lamps not to exceed 400 watts).

(b) With the pressure screw in the released position (out), close the line switch and note the brilliancy of the lamps and the voltage indicated. With the voltmeter test leads check the voltage across the lead side of the switch and note the voltage difference.

(c) Gradually tighten up on the carbon pile (by means of the screw) and note the effect on the lamps and the value indicated by the voltmeter. Pay special attention to observe whether the change takes place in steps, or is it gradual (a steady rise or fall).

(d) Make the same observations while gradually loosening (unscrewing) on the pressure screw of the rheostat.

QUESTIONS:

1. When the pressure screw was out (loose) was the ohmmeter reading at the highest resistance value or the lowest?
2. Under the conditions in question 1, were the lamps full brilliancy or dim?
3. Was the pressure tight (in) or loose (out) when the lamps were brightest?
4. Were the results uniform from no pressure on the discs to full pressure?

QUESTIONS (Continued)

5. What was the difference in voltage at the source of supply and at the lamps when the rheostat was in the loose (out) position?
6. What difference existed when in the tightest position (in)?
7. Why are many pieces of carbon used rather than one solid piece?
8. Does the resistance of the carbon pile rheostat ever reach absolute zero? Explain.

REFERENCES:

Standard Handbook for Electrical Engineers
Sect. 5-357, Page 534, McGraw-Hill

Electrical Measurements, By-Laws, Chapter 3
Page 153, McGraw-Hill

Bulletins #410, #420, Allen Bradley Co., Milwaukee

Information Lesson

COMMERCIAL APPLICATIONS OF ELECTRICAL DEVELOPMENT OF HEAT

In this Block you have discovered that heat is always produced in a wire when electricity flows through it. In fact, you will observe as you advance in your work, that all electrical equipment (whether a motor, generator, transformer, electric bulb, or any household appliance) will become warm to a greater or lesser degree when connected to a circuit. (By necessity, much heat is produced in flatirons, toasters, heaters, and similar appliances).

POWER WASTED IN HEATING CONDUCTORS:

Although the electrical development of heat has many valuable commercial applications, as will be pointed out to you in this lesson, nevertheless, in many cases, this production of heat often results in waste and sometimes creates a fire hazard. Every conductor carrying electricity produces heat but, under normal conditions, a conductor (wire) does not and should not even feel warm.. The reason for this is that the heat produced is radiated to the surrounding air as fast as it is produced, if the conductor is the proper size. This heat represents a loss, and as you will find later, it must be given careful consideration, especially in long transmission lines, etc. Similarly, the heat produced in a motor, generator, etc. and even the heat given off by the electric light bulb, represent a waste. It is evident, therefore, that whenever electricity passes through any conductor a certain amount of electrical energy is transformed into heat energy which is sometimes used and other times wasted.

The allowable and safe carrying capacities of conductors (wires) given in the National Electrical Code (N.E.C.) are determined by the currents which these conductors will carry continuously without injury to their insulations or material near them. Overloaded wires cause fires.

FUSES:

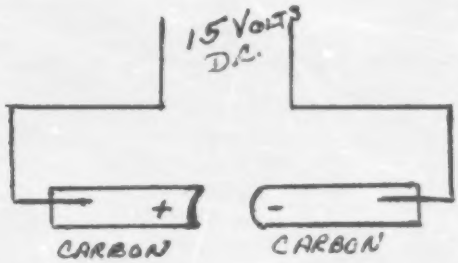
In this Block you discovered that, if you passed too much current through a wire, that wire became hot and the insulation took fire. Thus, it is evident that we must have an "electrical safety valve" to protect wiring systems from overloads and short circuits. One device used for this purpose is a fuse, the essential part of which is a strip of fusible alloy consisting of tin and lead. The fuse is inserted in the circuit and its operation depends on the heating effect of the current. The alloy, having a lower melting point than the wire of the circuit, melts when an overload or a short circuit occurs and thereby opens the circuit before any damage can be done..

HOUSEHOLD APPLIANCES

So far in this lesson we have considered the heating effect of an electric current as wasteful. However, all electrical appliances such as flatirons, waffle irons, toasters, coffee percolators, electric egg boilers, curling irons, electric tea kettles, table stoves and hot plates, electric corn poppers, electric doughnut bakers, egg cookers, heating pads, electrical ranges, heaters, water heaters, coffee urns, frying griddles, soldering irons, glue pots, etc. utilize the heating effect of an electric current. The heating element in these may be iron wire, nichrome wire (an alloy of nickel and chromium) etc. Nichrome and similar alloys are much superior to iron wire because they will better withstand oxidation..

ARC LAMPS - Experiment

CAUTION: HAVE YOUR INSTRUCTOR GUIDE YOU IN PERFORMING THIS EXPERIMENT.



Apply 15 or 20 volts direct current to two pointed carbon rods as shown in the above sketch. Have a piece of fibre or asbestos beneath the carbons. Touch the ends of carbon rods together. Do not have any combustible material nearby. Keep your face well away from the carbons. Holding each carbon rod in a separate fuse puller, gradually separate the carbon rods a short distance (about one-eighth inch). Keep your body and all inflammable materials well away from the arc. Note what happens. The arc, being harmful to the naked eye, should be observed through a piece of blue glass.

The brilliant arc of flames (called an electric arc) which you have just witnessed is produced as follows: when the carbon rods are touched together, a current flows between them. The points are heated due to the heating effect of an electric current. The points become so hot that the carbon vaporizes. So when the carbons are separated the current continues to flow across the space between the points because the space is filled with carbon vapor which is a much better conductor of electricity than air. This principle is made use of in the ARC LAMP used for stereopticon and motion-picture projectors, street lighting, etc.

ELECTRIC FURNACES:

An important industrial application of heating effect of an electric current is its use in electric furnaces. There are three general types of electric furnaces: (1) those where the electricity

is passed directly through heating elements, (2) Arc-Type Furnaces where the heat is produced by an electric arc, (3) Induction Furnaces which you will study in Block XXII.. A few of the many uses for electric furnaces are making carborundum, graphite, etc., melting, annealing, hardening, and heat treatment of steels, making steel, japanning, baking, enameling, etc.

QUESTIONS:

1. (a) What would happen if a circuit were not protected by fuses or circuit breakers and a short circuit occurred on the system?

   (b) Why is it dangerous to place a penny under a plug fuse?

2. (a) What is a fuse?

   (b) How does it work?

3. Consult reference books.

   (a) Describe the construction of a link fuse.

   (b) Does the N.E.C. permit the use of link fuses in homes, office buildings, etc? (See N.E.C.)

   (c) Describe the construction of a cartridge fuse.

   (d) Describe the construction of a plug fuse.

   (e) May plug fuses beused on a 230 volt circuit? (See N.E.C.)

   (f) Why are fuses commonly inclosed in an asbestos tube as in the cartridge fuses, or in a porcelain cup which screws into a socket as in the plug fuse? Hint: At the moment the "link" melts there is an arc across the gap..

4. Explain the construction and operation of an electric flat-iron.

5. Explain how advantage is taken of the heating effect of an electric current in the construction of electric heaters and similar appliances..

6. (a) When a knife switch is opened an arc takes place between the moving balde and the stationary jaws. If the switch is opened slowly serious arcing takes place. Is this arcing harmful? Why? Why should all switches be opened quickly?

   (b) Occasionally applying a thin film of pur vaseline to the blades and jaws of a knife switch is beneficial. Why?

7. Why are snap switches, toggle switches, etc., so designed that they operate with a <u>quick break</u>?

8. (a) If a residence is wired by the "knob and tube" method and a wire accidentally snaps behind a partition, is there any chance of a fire starting? Why?

   (b) If armored cable (B.X.) is used and a wire snaps behind a partition are the chances of a fire starting as great as when knob and tube work is used? Explain.

9. (a) What is an electric arc?

   (b) Give at least two commercial applications for the electric arc.

10. What is an electric furnace? Name some of its uses.

11. (a) What are the requirements of the National Electric Code with regard to making splices?

    (b) Why are these requirements made?

12. (a) On a certain installation two cables were joined together by soldering a lug to each cable and then bolting the two lugs together. If the electrician had been careless and left the bolts rather loose, what would have happened?

    (b) What would have happened if he had done a poor job soldering the lugs to the cable.

13. (a) What is welding?

    (b) Is all welding done by electricity?

    (c) What is the underlying principle of electric welding?

14. Explain how an incandescent lamp produces light.

15. List at least twelve commercial applications where the heating effect of electricity is useful.

16. Cite examples where the heating effect of electricity represents a loss.

17. Of what value to an electrician is the information given in this lesson..

18. If a cartridge fuse does not fit snugly into the fuse clips of the cut-our, permature blowing of the fuse results. Why?

REFERENCES

Jackson & Black,	Elementary Electricity and Magnetism 1942	Chapter XIX
Swoope's,	Lesson in Practical Electricity, 1948	Page 188
Slack,	Elementary Electricity, 1943	Page 32

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 31
Page 1 of 2

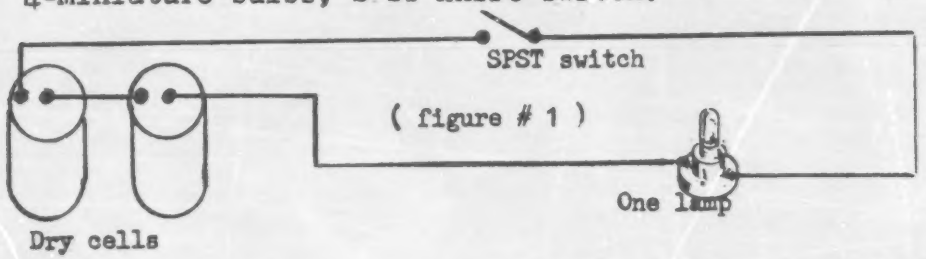
Series Circuits

PURPOSE:

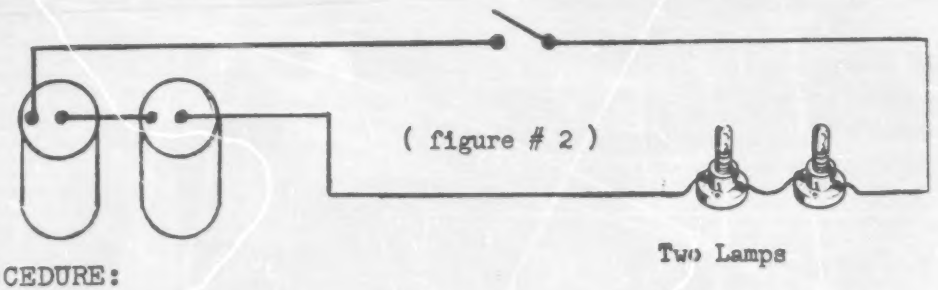
To discover whether or not lights can be put end to end (series) in a circuit.

MATERIALS USED:

2-dry cells, bell wire, 4-miniature receptacles, 4-miniature bulbs, SPST knife switch.



(figure # 1)



(figure # 2)

PROCEDURE:

Using 2-dry cells, connect one bulb in the circuit (Fig. 1). Close switch. Observe light.

Connect 2 bulbs in the circuit (Fig. 2). Close switch. Observe lights.

Connect 3 bulbs in the circuit, by disconnecting C wire and inserting the receptacle between the wire and the second receptacle. Close switch. Observe lights.

Connect 4 bulbs in the circuit by disconnecting the C wire from the third receptacle, and inserting the fourth receptacle, between the C wire and the third receptacle. Close switch. Observe lights. Draw a wiring diagram of 4 lights connected in series, for the instructor to approve.

Unscrew one bulb. Observe what happens.

Experiment No. 31
Page 2 of 2

QUESTIONS:

1. Bearing in mind how the lights behaved, answer the following:
   (a) Was there electricity flowing when 2 lights were connected?
   (b) Was there electricity flowing when 3 lights were connected?
   (c) Was there electricity flowing when 4 lights were connected?
2. When one bulb was unscrewed what change occurred?
3. Explain how you would connect 8 lights, like on a Christmas tree, in series?
4. State in your own words, what fact you have discovered in this experiment.
5. What use can you make of the fact you have just discovered?

REFERENCES:

Fundamentals of Electricity - McDougal Pages 50-54
Direct Current Fundamentals - Loper Pages 40-44

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 32
Page 1 of 3

Connecting and Reading Voltmeter

PURPOSE:

To learn the use of, and how to connect a voltmeter.

MATERIALS USED:

Power source, D C voltmeter (150 V), A C voltmeter (150 V), 115 V lamp, lamp receptacle, test leads, connection wire, 5 ohm resistor, 2-dry cells, SPST knife switch, DPST knife switch.

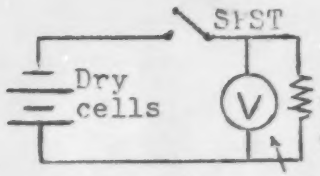


Fig.#1 0-150v

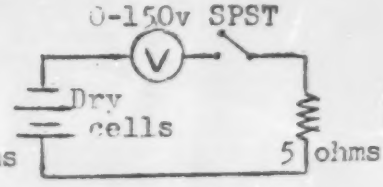


Fig.#2

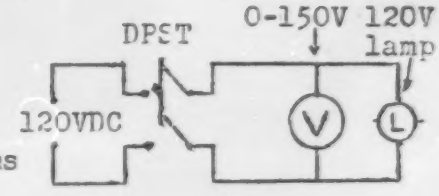


Fig.#3

EXPLANATORY NOTES:

When using voltmeters, the following facts must be considered:

1. Whether to use an AC or a DC voltmeter.
   CAUTION: NEVER USE A DC VOLTMETER ON AN AC CIRCUIT. AS YOU WILL LATER FIND, A DC VOLTMETER WILL NOT REGISTER ON AN AC CIRCUIT. ALSO, THE ALTERNATING CURRENT MAY CHANGE THE CALIBRATION OF THE INSTRUMENT.

   Most AC voltmeters may be used on DC circuits. On the scale or cover of the instrument will be information telling whether the voltmeter is to be used on AC or DC circuits, or both. Before using a voltmeter, always read the information on the scale and cover.

2. Select a voltmeter with a proper scale range.
   a. Make sure the scale range or the voltmeter is somewhat greater than the voltage of the circuit.
   b. A low voltage scale must never be used first.
   c. It is desirable to have the instrument read as near mid-scale as possible.

3. <u>Voltmeters are always placed across the circuit</u>.

EXPLANATORY NOTES (Continued)

4. Polarity of voltmeters. When DC voltmeters are used, the terminal marked (plus) must be connected to the positive side of the line. Otherwise, the needle or pointer of the instrument will not swing in the right direction and the connection will have to be reversed.

5. Handle meters with care. They are expensive, delicate instruments, easily injured with rough usage. Do not drop or handle roughly. Also, always place them in locations free from vibration, because vibrations will injure the jewels and pivots.

PROCEDURE:

1. Connect 2 dry cells, SPST switch, 5 ohm resistor as shown in Fig. 1. Connect battery tester across the resistor (parallel) Fig. 1. Close switch and read meter. Open switch, disconnect 5 ohm resistor and leave A and B wires open. Leave voltmeter connected. Close switch, note change, if any, open switch.

2. Reconnect 5 ohm resistor back into the circuit. Remove voltmeter and connect as shown in Fig. 2. Close switch, read meter. Open switch, remove 5 ohm resistor and connect wires A and B together. Close switch, note change, if any.

3. Connect DPST switch, lamp receptacle, voltmeter (150 V DC) as shown in Fig. 3. Connect circuit to a 120 V DC source. Close switch. If the needle should swing backward, instantly open the switch and reverse the voltmeter connections. Read the voltmeter to the nearest tenth of a division.

4. Open switch, Remove DC voltmeter and connect 150 V AC voltmeter into circuit. Connect the circuit to 120 V AC source. Close again close switch. Note change, if any.

QUESTIONS:

1. How should a voltmeter be connected?
2. What would happen if it were connected in series with the load?
3. a. Explain how you may determine the polarity of a DC circuit by means of a voltmeter.
   b. What other methods are you familiar with for finding the polarity of a circuit?
4. Suppose you had a 110 volt circuit, but you did not know whether it was AC or DC, what type of instrument would you use? Why?

QUESTIONS (Continued)

5. What is a voltmeter used for?
6. List all the precautions you must observe in using voltmeters.
7. What have you learned in this experiment?

REFERENCES:

Elementary Electricity - Slack 1943	Page 11
Lessons in Practical Electricity - Swoope's	Page 247

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Experiment No. 33
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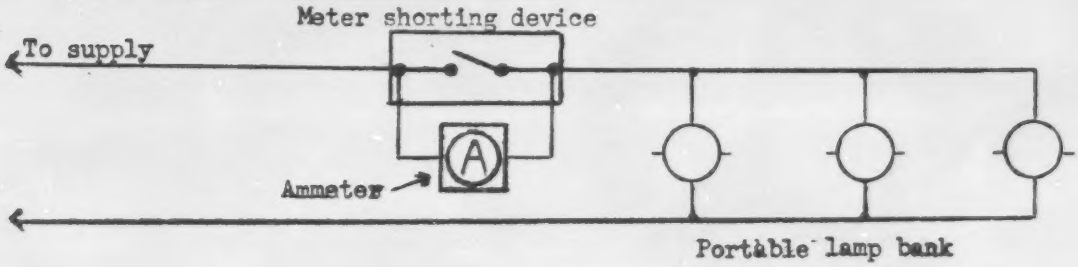
Connecting and Reading an Ammeter

PURPOSE:

To learn the use of an ammeter, and how to connect it.

MATERIALS USED:

Battery tester (0-35A,)-01V), D.C ammeter (5 ampere), A C ammeter (5 ampere), portable lamp bank, short circuiting block or switch.



EXPLANATORY NOTES:

1. In using ammeters the following facts must be considered:

   Whether to use an AC or a DC ammeter. Never use a DC ammeter on an AC circuit. (Same reason as given for voltmeter in Experiment 32).

2. Select an ammeter with a proper Scale Range. The rating of the instrument must correspond with the load to be measured. If the instrument is placed in a circuit whose current is greater than the scale range of the ammeter, it will be ruined. It is desirable to have the instrument read as near mid-scale as possible.

3. Whether or Not an External Shunt or Instrument Current Transformer Must be Used in Conjunction with the Ammeter. If the scale of an ammeter is marked to be used with an external shunt, never use the ammeter without the shunt because the ammeter would be instantly ruined if the shunt were ommitted. If AC ammeter scales are marked to be used with Current Transformer, never omit the current transformer because the ammeter will be ruined.

4. Ammeters Must be Placed in Series with the Load. CAUTION: NEVER CONNECT AN AMMETER ACROSS THE CIRCUIT BECAUSE IT WILL BE RUINED.

   In later experiments you will learn that ammeters have a very low resistance. There, if an ammeter

were connected across a line, as a voltmeter is, it would be instantly ruined.

5. Polarity of Ammeters. When DC ammeters are used, the current must enter the ammeter at the terminal marked. Otherwise the needle will not swing in the right direction and the connections will have to be reversed.

6. Handle Ammeters With Extreme Care.

PROCEDURE:

Part 1. DC Circuit

With the line switch open, connect the DC ammeter in series with the lamp bank. Make sure the circuit is DC. Connect a short-circuiting switch or block across the terminals of the ammeter as shown in Fig. 1. This is to be kept closed except when reading the ammeter. The short-circuiting switch or block is used to protect the ammeter from sudden rushes of large currents.

Have your connections checked by your instructor before closing the main switch. Close the main switch. Open the short-circuiting switch or block. Should the needle swing backward, open the main switch and reverse the ammeter connections. Take three readings of the ammeter with 2, 3, and 5 lamps, respectively, in the circuit.

Repeat the experiment using an AC ammeter and an AC supply. Before closing the main switch, have your connections checked by your instructor.

QUESTIONS:

1. What is an ammeter used for?
2. (a) Must a circuit be broken and an ammeter inserted in order to measure current? Explain.
   (b) Is an ammeter connected in series or parallel with the load?
   (c) Draw a sketch of this connection.
3. (a) How is a voltmeter connected?
   (b) Draw a sketch showing how a voltmeter should be connected.
4. Would it be all right to use a DC ammeter on an AC circuit? Do Not Try It.

QUESTIONS (Continued)

5. Make a list of all the precautions you must observe in connecting ammeters.
6. What do you think would happen if an ammeter were connected across a circuit? Do Not Try It.
7. What have you learned in this experiment?
8. Make a list of all the applications you are able to recall where ammeters are used.
9. (a) Explain how to measure the voltage and current across the load.

REFERENCES:

Elementary Electricity - Slack 1943	Pages 12-14
Lessons in Practical Electricity - Swoope's	Page 247
Fundamentals of Electricity - McDougal	Pages 145-152
Direct Current Fundamentals - Loper	Pages 112-114

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Electrical Experiments

Experiment No. 34
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Connecting and Reading an Ohmmeter

PURPOSE:

To learn the use of an ohmmeter, and how to connect it.

MATERIALS USED:

Various resistors, connection wire, ohmmeter.

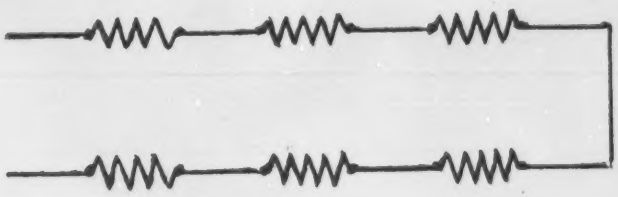

Fig.#1

EXPLANATORY NOTES:

In using ohmmeters the following facts must be considered:

1. The source of power to the circuit must be turned off. (The ohmmeter has its own dry cells for power).
2. The ohmmeter is used to measure the resistance regardless of whether the resistors are used on AC or DC.
3. Select the Proper Ohmmeter. Some ohmmeters are designed to read Low resistance, some High resistance, some both low and high. Learn about the meter assigned you for this experiment.
4. Since ohmmeters have their own power supply, polarity is not considered, as the ohmmeter will only read in one direction.
5. Ohmmeters have a selector switch that determines the reading on the scale. Such as, Rx1 reads direct, Rx10 multiply the reading by 10, Rx100 multiply by 100, etc.
6. Ohmmeters must be zeroed each time so as to calibrate the meter, as the battery gets weak.

   CAUTION: WHEN OHMMETER IS NOT IN USE ALWAYS TURN SELECTOR OFF THE OHM POSITION, OR DISCONNECT THE CELL TO GIVE THE CELL LONGER LIFE.

   REMEMBER: OHMMETERS ARE ONLY USED ON A CIRCUIT THAT HAS BEEN TURNED OFF.

Experiment No. 34
Page 2 of 2

PROCEDURE:

Connect several resistors as shown in Fig. 1. Place the ohmmeter probes across each resistor, one at a time, Test the resistors using the R1 setting. Note reading on scale.

Repeat using Rx10, Rx100, Rx1000 setting. Note the different positions on the scale for the different settings. Compare the readings.

QUESTIONS:

1. What is the ohmmeter used for?
2. How did the readings compare when using different ranges?
3. What precautions must you observe before using the meter to insure
4. What is the first step taken before using the meter to insure the meter reads accurate?
5. What advantage does the ohmmeter have over the voltmeter and ammeter for testing a circuit?
6. When the ohmmeter cannot be zeroed on the R1 setting, how can the meter be corrected?

REFERENCES:

Practical Electricity - Swoope's Pages 272-276
Direct Current Fundamentals - Loper Pages 116-117

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Electrical Experiments

Experiment No. 35
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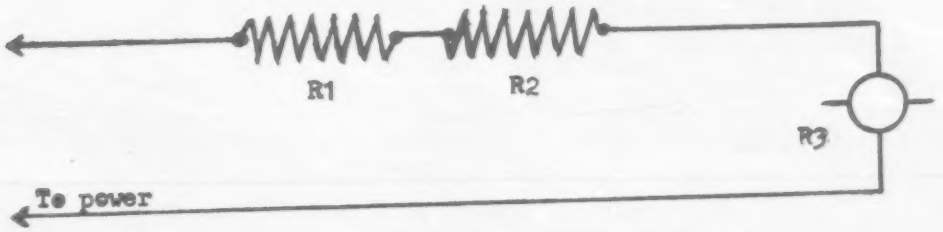
Series Circuit - Voltage Relations

PURPOSE:

To ascertain voltage drops across various resistances, and to determine the values of these voltage drops in a series circuit.

MATERIALS USED:

Two soldering irons (or similar load) two 100 watt, 115 volt incandescent lamps, two 50 watt, 115 volt incandescent lamps, three sockets, one 75/150 voltmeter, #14 AWG gage wire for leads.



PROCEDURE:

Connect two soldering irons in series across a 115 volt DC supply as shown in Fig. 1. R_1 and R_2 represent the soldering irons. Close the line switch. Read and record, in Table 1, the line voltage V_L; the voltage drop across R_1; voltage drop across R_2.

Repeat the experiment using:

(a) Two 100 watt, 115 volt incandescent lamps in series.

(b) Two 50 watt, 115 volt incandescent lamps in series.

(c) One soldering iron, one 100 watt, 115 volt lamp, one 50 watt, 115 volt lamp.

In each test, read and record the line voltage and the voltage drop across each resistance. In taking the voltmeter readings, use "probe leads" so that you may take all readings rapidly.

Experiment No. 35
Page 2 of 3

PROCEDURE (Continued)

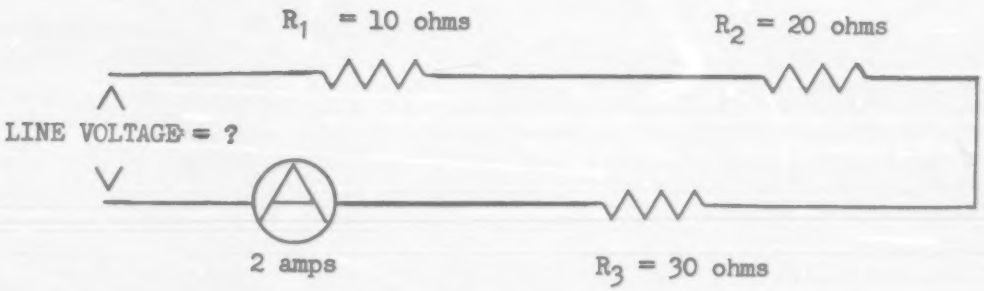
Table 1 - Series Circuit-Voltage

	Voltage Across R_1	Voltage Across R_2	Voltage Across R_3	Line Volt. V_L	Calculated Voltage
R_1 and R_2 are soldering irons					V_1 plus V_2
R1 and R2 are 100 watt, 115 volt lamps					V_1 plus V_2
R1 and R2 are 50 watt, 115 volt lamps					V_1 plus V_2
					V_1 plus V_2- V_3

R_1 = soldering iron
R_2 = 100 watt, 115 volt lamp,
R_3 = 50 watt, 115 volt lamp

QUESTIONS:

1. For each test performed, add up the voltage drops across the separate resistances and record in the last column headed "Calculated Voltage" of Table 1.
2. For each of the tests performed, compare the line voltage V_L with the sum of the voltages across the separate resistances.
3. Is the following statement true?
   The voltage across several resistances in series is equal to the sum of the voltages across the separate resistances. Prove your answer by your voltmeter readings.
4. Of what value to you is the fact you have discovered in this experiment?
5. What does the line voltmeter read in the diagram below? (Assume the voltage drop in the leads negligible.)



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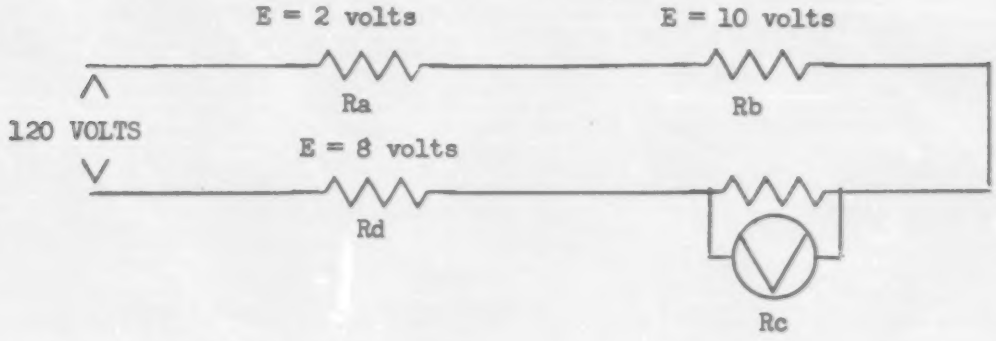
QUESTIONS (Continued)

6. What does voltmeter read across the resistance "C" in the circuit shown below? (Assume the voltage drop in the leads negligible).



REFERENCES:

Elementary Electricity - Slack	Pages 14-15
Fundamentals of Electricity - McDougal	Pages 53-54
Direct Current Fundamentals - Loper	Pages 42-43

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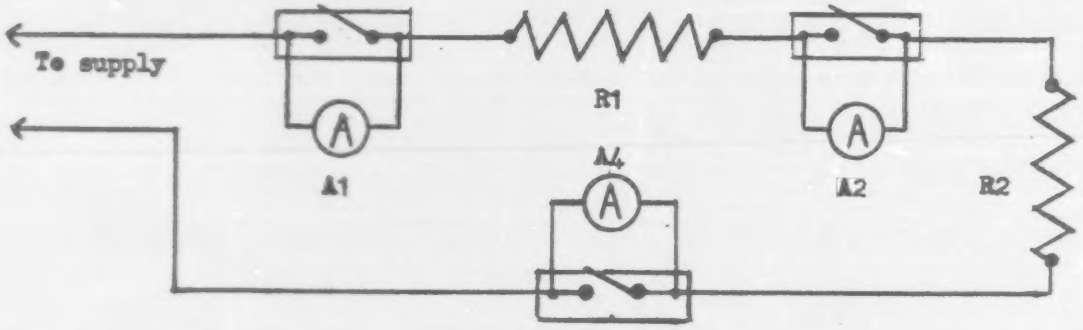
Series Circuit - Current Relations

PURPOSE:

To discover the distribution of current in a series circuit.

MATERIALS USED:

Two soldering irons, (or any similar load), two 100 watt, 115 volt incandescent lamps, two 50 watt, 115 volt incandescent lamps, three SPST short - circuiting switches for the ammeters, three sockets, D C ammeter (0-10), wire for leads.



PROCEDURE:

Connect two soldering irons R_1 and R_2 in series across a 115 volt D C supply. Break the circuit at three different places and insert SPST switches as shown in Fig. 1. Have your connections checked by your instructor before applying any current to the circuit.

Check the main switch.

To read the current at A, connect the ammeter across the short-circuiting switch S_1. With the short-circuiting switches S_1 and S_2 closed, open the short-circuiting switch S_1 and read the ammeter. To read the current at A_2, close the short-circuiting switch S_1 and read the ammeter. Follow a similar procedure to read the current at A_3. (Make sure the line voltage does not change between readings).

Open the main switch. Replace the two soldering irons by two 100 watt, 115 volt incandescent lamps. Close the switch and read the current at A_1, A_2, A_3.

Repeat the experiment, using two 50 watt, 115 volt incandescent lamps.

QUESTIONS:

1. Referring to Fig. 1:
   (a) Compare the ammeter readings A_1, A_2, A_3 when R_1 and R_2 were soldering irons.
   (b) Compare the ammeter readings A_1, A_2, A_3 when R_1 and R_2 were 100 watt incandescent lamps.
   (c) Compare the ammeter readings A_1, A_2, A_3 when R_1 and R_2 were 50 watt incandescent lamps.
2. Compare the ammeter readings when a soldering iron and a 100 watt bulb were used.
3. Is or is not the current the same in every part of a series circuit? Prove your answer by your ammeter readings.
4. Of what value to you is the fact you have just discovered?
5. If 8 amperes is leaving the positive post of an automobile storage battery, how much current is entering the storage battery at the negative post? Why?
6. If the intensity of the current entering a flat-iron is 5 amperes, what will be the intensity of the current on leaving?

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Series Circuit - Resistance Relations

PURPOSE:

To discover the law governing the resistance of a series circuit.

MATERIALS USED:

Three 10 ohm resistors, one 5 ohm resistor, one 3 ohm coil, ohmmeter, wire for leads.

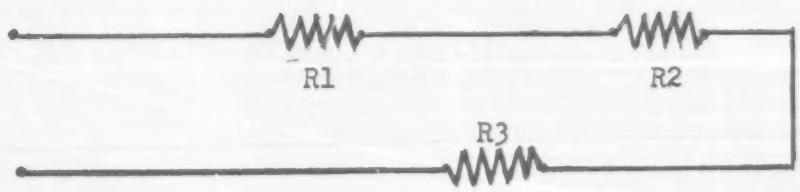

Fig.#1

PROCEDURE:

Connect the three 10 ohm resistors as shown in Fig. 1.
Measure the resistance of each resistor.
Measure the resistance of all three together.
What does this prove to you?
Connect one 10 ohm, one 5 ohm and one 3 ohm in series.
Measure the resistance of each resistor.
Measure the resistance of all three together.
What does this prove to you?

QUESTIONS:

1. Is the following statement true?
   "The resistance of several resistances in series is the <u>sum</u> of the separate resistances." Prove your answer by the results obtained in this experiment.
2. Which of the following is correct?
   $R_t = R_1$ plus R_2 plus R_3
   $R_t = R_1 - R_2 - R_3$
   Prove your answer by the results obtained in this experiment.

QUESTIONS (Continued)

3. Three resistances of 5 ohms, 7.102 ohms and 9.623 ohms are connected in series. What is the resistance of the combination?
4. A certain street lighting circuit is made up of 40 lamps in series. If each lamp has a hot resistance of 12.8 ohms, what is the resistance of the circuit?
5. State three laws governing series circuits.
   (a) Law of Current.
   (b) Law of Voltage.
   (c) Law of Resistance.
6. Of what value to you is the fact you have discovered in this experiment?

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Parallel Circuit

PURPOSE:

To discover whether or not conductors can be put side by side (parallel) in a circuit.

DEFINITION:

Conductors connected side by side so that the current divides them are said to be in parallel. Fig. 1 shows coils connected in parallel, and Fig. 2 shows lamps connected in parallel.

MATERIALS USED:

Make 4 coils, using 4 pieces of #22 magnet wire and wind around a pencil. Use a No. 6 Dry cell magnetic compass, 3 flashlight bulbs, 3 miniature base lamp-holders.

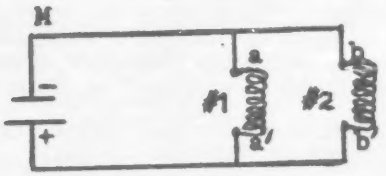

Fig. #1

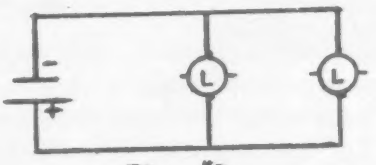

Fig. #2

PROCEDURE:

Proceed as follows to connect two coils in parallel: Splice end "a" of coil #1 and end "b" of coil #2 to a common wire "M" running from the dry cell as shown in Fig. 1. Splice the other end (a') of coil #1 and the other end of (b') of coil #2 to a second common wire "N" running from the other terminal of the dry cell (Fig. 1).

With one end of wire "M" and one end of wire "N" connected to the dry cell terminals and the other ends separated as shown in Fig. 1; explore both coils with a compass. Note the action, if any, of the compass needle.

Disconnect the wires "M" and "N" from the dry cell and proceed to connect coil #3 in parallel with the other two coils by splicing the end "c" to wire "M" and the end c' to wire "N" as shown in Fig. 2.

Connect the wires to the terminals of a dry cell and explore all three coils with a compass. Note the action, if any, of the compass needle.

PROCEDURE (Continued)

Proceed to connect a fourth coil in parallel with the other three. Proceed in a manner similar to that when connecting the third coil in parallel. Make a wiring diagram showing the four coils in parallel.

With the wires "M" and "N" connected to the dry cell terminals, explore all four coils with a compass. Note the action, if any, of the compass needle.

Repeat experiment using flashlight bulbs, in miniature receptacles, in place of the coils. (Fig. 2)

Connect two lamps in parallel as shown in Fig. 2. Connect the wires "M" and "N" to the dry cells. Do the lamps light? Also explore all sections of the circuit with a compass noting the action, if any, of the compass needle.

Unscrew one of the bulbs. Does the other lamp still burn?

Repeat with three lamps connected in parallel. Try screwing (a) one bulb, (b) two bulbs.

QUESTIONS:

1. In your own words explain the difference between a series circuit and a parallel circuit.
2. Bearing in mind how the compass needle behaved, answer the following:
   (a) Was there electricity flowing in both coils when two were connected in parallel?
   (b) Was there electricity flowing in all coils when three were connected in parallel?
3. (a) What happened when one or more of the bulbs in the parallel circuit was loosened? Explain.
   (b) Compare this with the series circuit in Experiment 30.
4. On many of the Christmas tree lighting outfits, if one light burns out the rest of the lights on that circuit go out; while in other Christmas tree lighting outfits the burning out of a bulb does not affect the others.
   (a) How do you account for this difference?
   (b) Draw a wiring diagram of each set and label the type of circuit.
5. State in your own words, what fact you have discovered in this experiment.
6. What use can you make of the fact you have discovered.

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Experiment No. 39
Page 1 of 2

Parallel Circuit-Voltage Relations

PURPOSE:

To study the distribution of voltage drops in a parallel circuit.

MATERIALS USED:

Three 60 watt 115 volt lamps; three 100 watt, 115 volt lamps, three 25 watt, 115 volt lamps, four sockets, D C voltmeter (150 volt range), wire for leads, soldering iron.

SKETCH:

The student is to draw a sketch showing three lamps and one soldering iron connected in parallel across a 115 volt D C line.

PROCEDURE:

Connect two 60 watt, 115 volt incandescent lamps in parallel across a 115 volt D C line. Read, and record in Table 1, the line voltage and the voltage across each lamp. Call the voltage across these lamps V_1 and V_2 respectively.

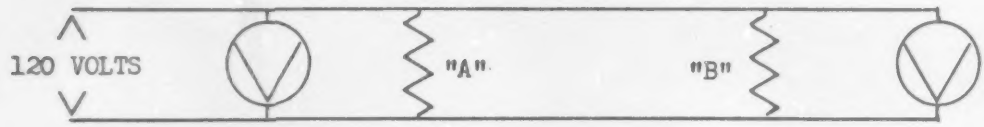
Repeat the experiment using the various parallel combinations called for in Table 1. For each test, read and record the line voltage and the voltage across each lamp or appliance.

Table 1 - Parallel Circuit -- Voltage

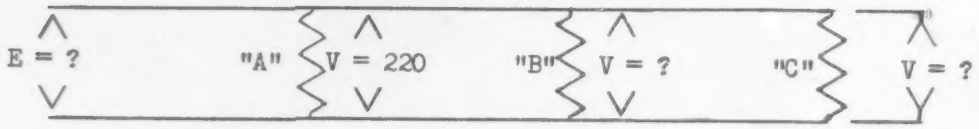
Parallel combinations	Line Voltage	Voltage drop across each lamp or appliance			
		V_1	V_2	V_3	V_4
Two 60 watt lamps					
Three 60 watt lamps					
Two 100 watt lamps					
Three 100 watt lamps					
Two 25 watt lamps					
Three 25 watt lamps					
One 60 watt, one 100 Watt					
One 25 watt lamp					
One soldering iron					

QUESTIONS:

1. For each test performed, compare the line voltage with that across each individual branch.
2. Is or is not the following true?
   "The voltage across several resistances in parallel is the same for all." Prove your answer by your voltmeter readings.
3. Compare the law governing Voltage for a series circuit with that for a parallel circuit.
4. Of what value to you is the fact you have discovered in this experiment?



5. In the circuit diagram shown above (a) what is the voltage across "A"? Why? (b) What is the voltage across "B"? Why?



6. If the voltage across "A" in the circuit diagram above is 220 volts, what is the voltage across the resistance "B", across the resistance "C", and across the line?
7. An e.m.f. of 115 volts is impressed on a parallel circuit which consists of four branches of 2, 3, 4, and 11 ohms respectively. What is the voltage across the 3 ohms and across the 11 ohm branch?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 40
Page 1 of 2

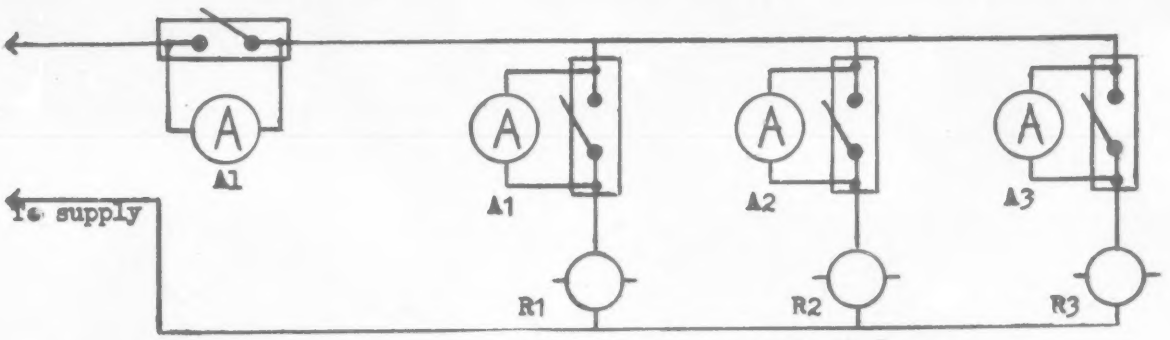
Parallel Circuit - Current Relations

PURPOSE:

To study the distribution of current in a parallel circuit.

MATERIALS USED:

Three 60 watt 115 volt lamps, three 100 watt, 115 volt lamps, three 25 watt, 115 volt lamps, four short-circuiting switches for the ammeters, three sockets, four 0-5 ampere ammeters, wire for leads.



R_1, R_2, R_3 represent lamps.

A_L is the line ammeter.

A_1 measures the current passing through R_1.

A_2 measures the current passing through R_2.

A_3 measures the current passing through R_3.

PROCEDURE:

Connect the lamp sockets and ammeters as shown in Fig. 1, using single pole switches to short circuit the ammeters. If four ammeters are not available, the experiment may be performed with one ammeter. If only one ammeter is used, it will be necessary to shift it from one part of the circuit to another.

Place three 60 watt, 115 volt lamps in the parallel connected sockets (Fig. 1). Close the switch and read all ammeters. (If only one ammeter is available, change from branch to branch and to the main line). Record the readings in Table.

Experiment No. 40
Page 2 of 2

PROCEDURE (Continued)

Open the main switch; remove the 60 watt lamps from the sockets. Place three 100 watt, 115 volt lamps in the sockets. Close the main switch and read the current at A_L, A_1, A_2, A_3. Record the readings in Table.

Repeat the experiment using three 25 watt, 115 volt lamps.

Repeat the experiment using one 60 watt lamp, one 100 watt lamp, and one 25 watt lamp.

Table 1 - Parallel Circuit - Current

Parallel Combinations	Current in Branches A_1 A_2 A_3	Line Current A_L	Sum of Ammeter Readings $A_1 + A_2 + A_3$
1. Three 60 watt lamps			
2. Three 100 watt "			
3. Three 25 watt lamps One 60 watt lamp			
4. One 100 watt lamp One 25 watt lamp			

QUESTIONS:

1. For each test performed, add up the ammeter readings in each of the three branches ($A_1+A_2+A_3$). Record this in the last column of the Table.
2. For each of the tests performed, compare the line current with the sum of the currents flowing through the branches.
3. Is or is not the following true?
   In a parallel circuit, the current through the combination is equal to the sum of the current through the parts.
   Prove your answer by your ammeter readings.
4. Compare the law governing current for a series circuit with that for a parallel circuit.
5. Of what value to you is the fact you have discovered in this experiment?
6. Three resistances A, B, C, are connected in parallel. The total current flowing is 46.1 amperes. If the current flowing through A is 9.789 amperes and through B is 21.62 amperes, what is the current flowing through C?
7. As you turn on more lamps in your home, is there any change in the current flowing through the meter? Explain.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 41
Page 1 of 2

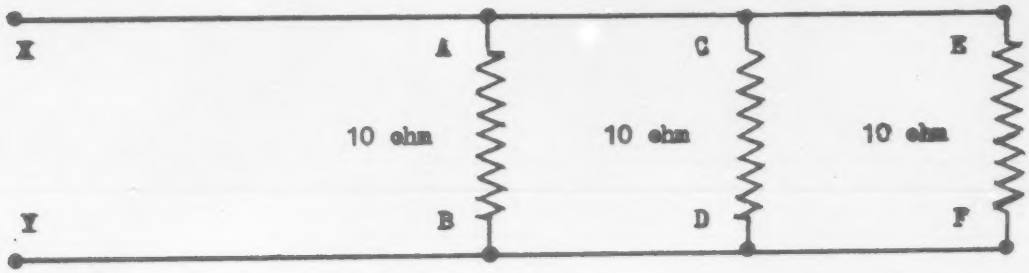
Parallel Circuit - Resistance Relations

PURPOSE:

To discover the law governing the resistance of a parallel circuit.

MATERIALS USED:

Three 10 ohm resistors, one 25 ohm resistor, one 5 ohm resistor, ohmmeter, wire for leads.



CAUTION: NEVER USE AN OHMMETER ON A LIVE CIRCUIT.

PROCEDURE:

Using ohmmeter, measure each resistor assigned by instructor. Connect three - 10 ohm resistors into a circuit as shown in sketch, rechecking each resistor just before making final connection on each.

Test circuit across the points X and Y, A and B, C and D, E and F, recording meter reading after each test.

Replace resistor across E and F, by a 5 ohm resistor. Repeat readings. Record as above.

Replace resistor across E and F, by a 25 ohm resistor. Repeat reading and record as above.

Replace resistor across C and D, by a 5 ohm resistor. Repeat reading, record as above.
Compare all the readings.

NOTE: NOTICE THAT THE TOTAL RESISTANCE IS ALWAYS SMALLER THAN THE BRANCH WITH THE LOWEST RESISTANCE.

QUESTIONS:

1. Remembering the series circuit resistance relations, can you add up the resistors to find the total resistance? Explain.

QUESTIONS (Continued)

2. Consult a Reference Book and answering the following:

   What is conductance?
   What is the unit for conductance?
   Compare conductance and resistance.

3. Why is the following statement true?
   "In a parallel circuit, the conductance of the combination is equal to the sum of the conductance of the parts".

4. If a resistor has a resistance of 3 ohms, what is the conductance?

5. When the three 10 ohm resistors were connected into the circuit, why does the meter read less than 10 ohms when placed across points C and D?

6. When one of the 10 ohm resistors was placed by the 5 ohm resistor, why did the meter read lower?

7. Show how you would connect five 110 volt lamps on a:

   (a) 550 volt circuit,
   (b) 110 volt circuit.

   Give your reasons for so doing.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 42
Page 1 of 7

OHM'S LAW: $I = \frac{E}{R}$

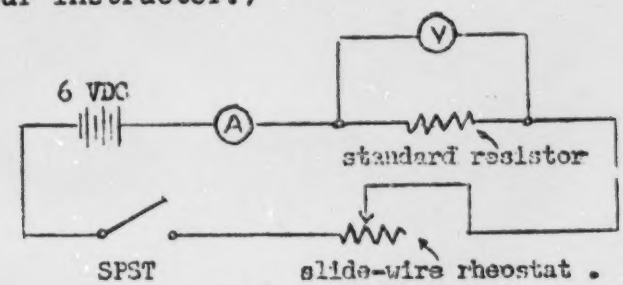
PURPOSE:

To discover whether or not, in an electric circuit, the current is equal to the electromotive force divided by the resistance.

$$(\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}})$$

MATERIALS USED:

6 V. DC supply, 3 ampere ammeter, 15 volt voltmeter, standard resistance spools, s. p. battery switch, short-circuiting block for ammeter, slide-wire rheostat, (or equivalent material and equipment as designated by your instructor.)



Fig#1

PROCEDURE:

CAUTION: DO NOT CONNECT ANY LEADS TO THE POWER SUPPLY UNTIL YOUR CONNECTIONS HAVE FIRST BEEN CHECKED BY YOUR INSTRUCTOR. IMPROPER CONNECTIONS WILL RUIN THE AMMETER.

Review the experiments on how to connect voltmeters and ammeters.

With the switch open, make the connections as shown in Fig. 1. The slide-wire rheostat is connected into the current so as to prevent the possibility of excessive currents. In no way does it enter into the purpose of the experiment. After the slide wire has once been set (consult your instructor), do not change it throughout the experiment.

The resistance is represented in the diagram by the zigzag line, and for the first test, use the 3 ohm standard resistance. Be sure to use a short circuiting switch or block with the ammeter (now shown in sketch).

PROCEDURE (Continued)

Part I - How Resistance Affects the Current.

After your connections have been checked by your instructor, connect the free leads to the power supply posts. Before closing the switch, notice the positions of the needle of both ammeter and voltmeter. If there is any reading below or above zero, this reading must be added to, or subtracted from, the observer readings taken when the current is flowing (or else set the needle on zero by the "zero shifter".)

CAUTION: DO NOT TOUCH THE ZERO SHIFTER WITHOUT FIRST CONSULTING YOUR INSTRUCTOR.

Close the switch and read both the volmeter and the ammeter at the same time. (Have your partner read one of the instruments). Read each instrument to the nearest tenth of a division and record the readings in Table 1. Take at least three sets of readings for each test.

Repeat the experiment using a 6 ohm coil.

Repeat the experiment using a 9 ohm coil.

Repeat the experiment using a 12 ohm coil.

Part II. How Voltage Affects the Current.

Repeat the experiment with the three ohm coil connected across (a) one cell of the storage battery, (b) two cells of the storage battery.

QUESTIONS and PROBLEMS

According to Ohm's Laws

$$\text{Current} = \frac{\text{Electromotive Force}}{\text{Resistance}}$$

which may be written

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

which also may be written

$$I = \frac{E}{R}$$

When: I - Intensity of current in amperes.
E - Electromotive force in volts.
R - Resistance in ohms.

QUESTIONS AND PROBLEMS (Continued)

If Ohm's Law is true, the ammeter reading you obtained in each case should equal the voltmeter reading divided by the resistance. Example: Suppose the voltmeter reads 5.97 volts when the 3 ohm coil is in the circuit, what should the ammeter read?

By Ohm's Law, $I = \frac{E}{R}$

Substituting 5.97 for E and 3 for R
then, $I = \frac{5.97}{3} = 1.99$ amperes. (Ans.)

Therefore, the ammeter should read 1.99 amperes if the formula is true.

1. From your voltmeter readings and the values of resistance stamped on the standard resistance spools, calculate the value of the current for each of the tests you performed. Record your calculations in the extreme right hand column of Table 1.

TABLE I (Part I)

Resistance (Ohms)	Voltmeter (Volts)	Ammeter Reading (Amperes)	Calculated Amperes ($I = \frac{E}{R}$)
3			
6			
9			
12			

TABLE I (Part II)

Resistance (Ohms)	Voltmeter Reading (Volts)	Ammeter Reading (Amperes)	Calculated Amperes ($I = \frac{E}{R}$)
3			
3			
3			

QUESTIONS AND PROBLEMS (Continued)

2. Compare the calculated values of current with the actual ammeter readings you obtained while performing the experiment. Is Ohm's Law true? Explain.
3. What fact have you discovered in this experiment?
4. Of what value to you is this fact?

EXPLANATORY NOTES: ELECTRICAL MATHEMATICS

If the following suggestions are carefully observed in performing problems in electrical mathematics, you will encounter but few difficulties.

1. Carefully study the problem submitted to find out (a) what data is given, (b) what you are to find.
2. Draw a sketch of the circuit referred to in the problem and properly label it. This will help you visualize the problem.
3. Select the proper formula or rule.
4. Substitute the known values, in the formula or rule, accurately.
5. Carefully perform the operations called for in the formula or rule.
6. Arrange your work in order. This will greatly reduce the possibilities of making mistakes.
7. Do all the arithmetic on the sheet you submit to your instructor.
8. Properly label your answer. For example, if you have found the resistance of a spool of wire to be 5 ohms, do not write the figure "5" only, but write "ohms" after it.
9. Write "Ans." after your answer.

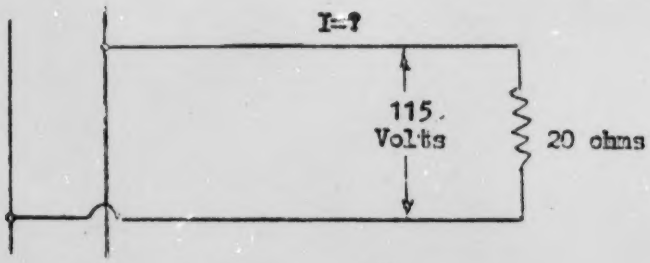
EXAMPLE: What current flows through a resistance spool of 20 ohms when 115 volts is applied across it?

SOLUTION: Following the above suggestions, proceed as follows:

(1) Upon reading the problem, we find (a) the following information given: We have a resistance spool of 20 ohms and across this spool is applied an e.m.f. of 115 volts, (b) we are to find what current flows through the 20 ohm coil.

(2) Circuit diagram will be as shown below:

EXPLANATORY NOTES - ELECTRICAL MATHEMATICS (Continued)



(3) The proper formula is $I = \frac{E}{R}$.

(4) Substituting in the formula, 115 for E and 20 for R, we have:

$$I = \frac{115}{20}$$

(5,6,7) Performing the operations called for, arranging the work neatly, and showing all arithmetic on your paper. Divide 115 by 20.

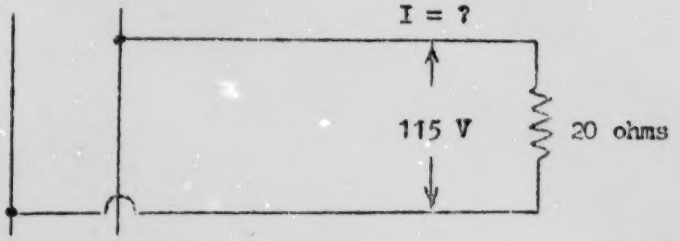
$$\begin{array}{r|l} & 5.75 \\ \hline 20 & 115.00 \\ & \underline{100} \\ & 150 \\ & \underline{140} \\ & 100 \\ & \underline{100} \end{array}$$

(8) Properly label the answer: I = 5.75 amperes.

(9) 5.75 amperes. (Ans.)

The above shows you the order of procedure in solving any problem. Of course, you need not list the nine steps. On your paper, the above proglem should appear as follows:

What current flows through a resistance spool of 20 ohms when 115 volts is applied across it?



$I = \frac{E}{R}$

$I = \frac{115}{20}$

I = 5.75 amperes. (Answer)

$$\begin{array}{r|l} & 5.75 \\ \hline 20 & 115.00 \\ & \underline{100} \\ & 150 \\ & \underline{140} \\ & 100 \\ & \underline{100} \end{array}$$

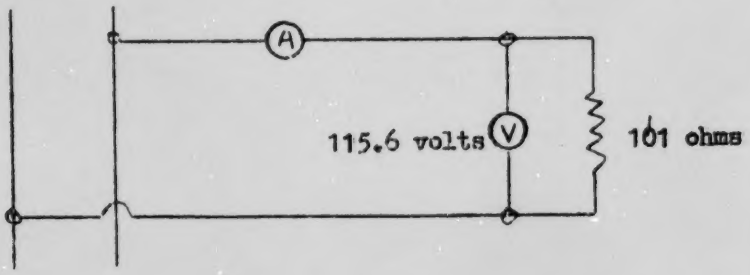
QUESTIONS AND PROBLEMS (Continued)

5. What current flows through a resistance of 50 ohms when an electromotive force of 115 volts is applied across the resistance?
6. What current flows through a resistance of 423.15 ohms when 220 volts is applied across it?
7. The hot resistance of an electrical laundry iron is 22 ohms. What current does the iron draw when operated on a 115 volt circuit?
8. A 110 volt, 20 c.p. carbon lamp has a hot resistance of 242 ohms. What current does it draw from a 110 volt line?
9. If the hot resistance of a car heater is 110 ohms, what current does the heater draw from a 550 volt line?
10. The voltage drop across a rheostat is 100 volts. If the resistance of the rheostat is 400 ohms, what is the current?
11. The difference in potential between the two sides of a lighting circuit is 115 volts. What current will a tungsten lamp, having a hot resistance of 480 ohms, draw when connected across this line?
12. A certain coil of wire has a resistance of 600.12 ohms. What current flows through the coil when connected to two points in a circuit between which there is a difference of potential of 0.015 volts?
13. What current does an electric curling iron, having a hot resistance of 60 ohms, draw from a 115 volt circuit?
14. What current does a 481 ohm warming pad draw from a 115 volt circuit?
15. The resistance of an ammeter is very small, often only about 0.001 ohm. Therefore, the ammeter will offer very little resistance to the flow of current. (NEVER ATTACH AN AMMETER ACROSS A CIRCUIT BECAUSE IT WOULD BURN OUT INSTANTLY AND BE RUINED).

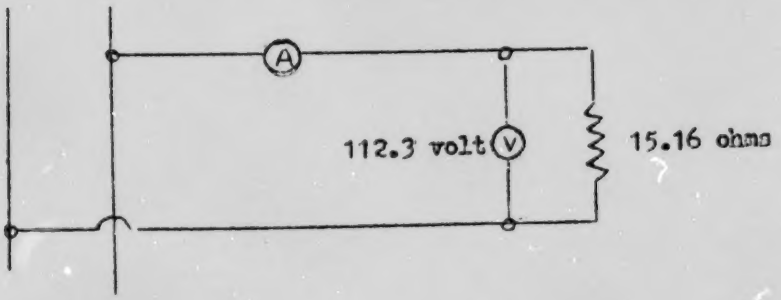
    Calculate what current would tend to flow if an ammeter with resistance of 0.001 ohms were, by mistake, connected across a 110 volt circuit.
16. The resistance of the 150 volt scale of a certain D.C. voltmeter is 14,522 ohms. What current passes through this instrument when connected across a 115 volt line?

QUESTIONS AND PROBLEMS (Continued)

17. What does the ammeter read in the circuit shown below:



18. What range ammeter should be used for the circuit shown below? Why? Show all calculations.



REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black, 1942	Page 35
Elementary Electricity - Slack 1943	Page 8
Electricity - Burns 1930	Page 40
Lessons in Practical Electricity - Swoope's 1948	Page 127
Elements of Electricity - Timbie 1937	Page 14

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 43
Page 1 of 4

OHM'S LAW: $E = IR$

PURPOSE:

To discover whether or not, in an electric circuit, the voltage is equal to the current multiplied by the resistance.

EXPLANATORY NOTES:

In Exp. 42, the formula, $I = \frac{E}{R}$, was used. You discovered that if the voltage and the resistance of a circuit were known, you could calculate the current flowing in that circuit, by the use of this formula. By mathematics, the formula $I = \frac{E}{R}$, may be changed to read: $E = I \times R$

In other words, Ohm's Law may also be stated in the following form:

Electromotive Force = Current x Resistance

Rewritten thus: Volts = Amperes x Ohms

Also thus: $E = I \times R$

If this is true, the voltmeter reading you obtained in each case in Exp. 42 should be equal to the ammeter reading multiplied by the resistance.

EXAMPLE: Suppose the ammeter read 1.99 amperes when the 3 ohm coil was in the circuit. What should the voltmeter read?

$E = I \times R$
substituting, $E = 1.99 \times 3$
multiplying, $E = 5.97$ volts

The voltmeter should read 5.97 volts, if the formula is true.

QUESTIONS AND PROBLEMS:

1. From your ammeter readings (taken in Exp. 42) and the value of resistance stamped on the standard resistance spools, calculate the voltage for each of tests you performed in Exp. 42. Record your calculations in the extreme right hand column of Table below:

QUESTIONS AND PROBLEMS (Continued)

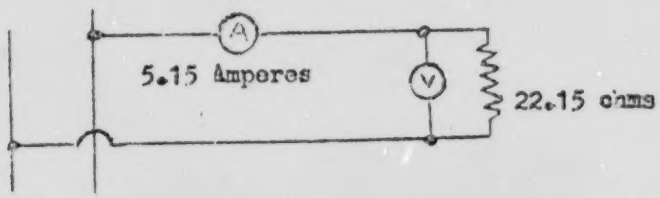
PART I

Resistance (Ohms)	Ammeter Reading (Amperes)	Voltmeter Reading (Volts)	Calculated Volts E = IxR
3			
6			
9			
12			

PART II

Resistance (Ohms)	Ammeter Reading (Amperes)	Voltmeter Reading (Volts)	Calculated E = IxR
3			
3			
3			

2. Compare the calculated values of voltage with the actual voltmeter readings you obtained while performing Exp. 42. Is Ohm's Law, written in the form E=IR, true? Explain.
3. State in your own words, what you have discovered in this experiment.
4. Of what value to you is this fact?
5. What does the voltmeter read in the circuit shown below?



6. What will be the reading of a voltmeter which is connected across a 4 ohm resistance through which a current of 57.5 amperes is flowing?
7. What voltage is needed to cause a current of 0.12 amp. to flow through a resistance of 1068.1 ohms?
8. How much will a voltmeter read if it is connected across a 25 ohm resistance coil through which 0.972 ampere is flowing?
9. A certain flatiron of 21.1 ohms can safely carry 5.7 amperes. How high can the voltage run?

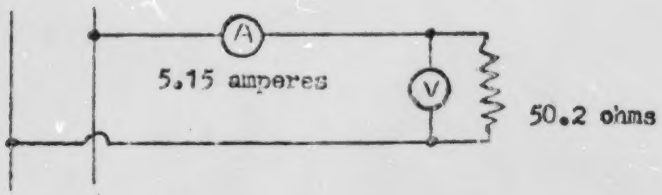
QUESTIONS AND PROBLEMS (Continued)

10. What should be the reading of a voltmeter connected across an electric heater whose resistance is 22.12 ohms, if an ammeter indicates the heater is taking 9.98 amperes?

11. (a) What is the voltage drop across an ammeter shunt whose resistance is 0.004 ohm when 50 amperes is flowing through the shunt?

    (b) If the ampere rating of this shunt is 50 amperes, what is its millivolt (M.V.) rating?

12. You wish to measure the voltage in the circuit shown below. A voltmeter with what range should be used? Why? Show all calculations.



13. If 1000 feet of #10 B & S copper wire has a resistance of 1 ohm, what is the voltage drop across this 1000 foot wire when 25 amperes is flowing through it?

14. If 1000 feet of bell wire has a resistance of 6.374 ohms, what is the voltage drop across this 1000 foot wire when 3 amperes is flowing through it?

15. A certain coil of wire having a resistance of 22.1 ohms drew a current of 5.3 amperes when connected to a lighting circuit. Find the voltage of the lighting circuit.

16. (a) What is the voltage of the lighting circuits in your home?

    (b) What is the voltage of the lighting circuits in the machine shop and the carpenter shop of your trade school?

    (c) What is the voltage of the circuit supplying power to the machinery in the carpenter shop and machine shop of your trade school?

17. Why does the N.E.C. require that voltage be a part of the information stamped on the nameplate of all electrical appliances?

18. If it takes 115.1 volts to send 10 amperes through a certain coil, how many volts would be required to send 20 amperes through that same coil?

QUESTIONS AND PROBLEMS (Continued)

19. What pressure is needed to force 5 amperes through an appliance of 21 ohms?

20. What voltage is needed to send 5.5 amperes through the appliance in Problem 19?

21. What electromotive force is needed to make 4 amperes flow through the appliance in Problem 19?

22. In Problem 19, 20, and 21, the terms pressure, voltage and electromotive force were used respectively. Do or do not these terms all mean the same thing? Explain.

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black, 1942	Page 35
Elementary Electricity - Slack 1943	Page 8
Electricity - Burns 1930	Page 40
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CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 44
Page 1 of 6

OHM'S LAW: $R = \frac{E}{I}$

PURPOSE:

To discover whether or not, in an electric circuit, the resistance is equal to the voltage divided by the current.

EXPLANATORY NOTES:

In Exp. 42, by use of the formula $I = \frac{E}{R}$, we were able to calculate the current flowing in a circuit when the voltage and resistance of that circuit were known.

In Exp. 43 by the use of the formula E = I X R, we were able to calculate the voltage when the current and resistance were known.

By mathematics, the formula $I = \frac{E}{R}$ may be changed to read: $R = \frac{E}{I}$.

In other words, Ohm's Law may also be written in the following form:

$$\text{Resistance} = \frac{\text{Electromotive Force}}{\text{Current}}$$

rewritten thus: $\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$

also thus: $R = \frac{E}{I}$

If this is true, than the voltmeter reading divided by the ammeter reading for each of the tests in Exp. 42 should equal the resistance in ohms stamped on the standard resistance coil.

EXAMPLE: Suppose the voltmeter read 5.97 volts and the ammeter read 1.99 amperes when a certain coil was tested in Exp. 42. What is the resistance of that coil?

By Ohm's Law, $R = \frac{E}{I}$

substituting, $R = \frac{5.97}{1.99}$

dividing, $R = 3$ ohms

The resistance stamped on that standard resistance spool should be 3 ohms if the formula is true.

QUESTIONS AND PROBLEMS:

1. From your voltmeter and ammeter readings obtained for each of the tests you performed in Exp. 42, calculate the resistance of each of the standard resistance spools used. Record your calculations in the extreme right hand column of Table 1, below.

Voltmeter Reading (Volts)	Ammeter Reading (Amperes)	Resistance Stamped on Spools (Ohms)	Calculated Resistance (Ohms) $R = \frac{E}{I}$
Part I			
		3	
		6	
		9	
		12	

Voltmeter Reading (Volts)	Ammeter Reading (Amperes)	Resistance Stamped on Spools (Ohms)	Calculated Resistance (Ohms) $R = \frac{E}{I}$
Part II			
		3	
		3	
		3	

2. Compare the calculated values of resistance with the actual resistance stamped on the spools.

   Is Ohm's Law, written in the form $R = \frac{E}{I}$ true? Explain.

3. Explain by use of a diagram how you could determine the resistance of a lamp by means of a voltmeter and ammeter.

EXPLANATORY NOTES:

Ohm's Law is the foundation of all scientific knowledge of electricity. Therefore, commit to memory Ohm's Law in its three forms. This will save you much work.

The following diagram may be used for remembering Ohm's Law, in any of its three forms.

EXPLANATORY NOTES (Continued)

By placing a finger over the symbol which represents the quantity that you wish to find, the relative positions of the remaining terms will tell you what to do to find it.

Example No. 1. Suppose you want to find the current in a circuit, the voltage and resistance of which you already know. To find the current, place your finger over "I" on the circle diagram. The sketch shows you that to find the current, you must use a mathematical expression wherein E is placed over R thus:

$\frac{E}{R}$ which means you must divide E (Voltage) by R (resistance).

In other words, the formula to use is $I = \frac{E}{R}$.

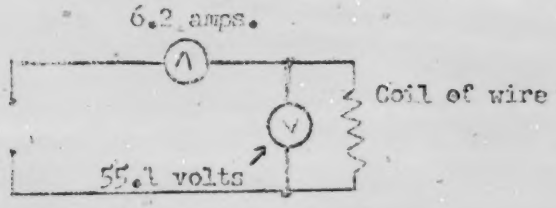
Example No. 2. What is the formula for finding voltage? Place your finger over "E". The sketch shows that in order to find voltage, you must use a mathematical expression wherein I is coupled with R thus: IR, which means you must multiply I (current) by R (resistance). E = IR.

Example No. 3. What is the formula for finding resistance? With your finger, cover up "R" on the circle. Then the circle indicates $\frac{E}{I}$.

Therefore, to find resistance divide voltage by current. $R = \frac{E}{I}$.

QUESTIONS AND PROBLEMS:(Continued)

4. What is the resistance of the coil of wire shown in the diagram below?



5. What is the resistance of a circuit when the electromotive force is 118 volts and the current flowing is 2.35 amperes?
6. If a certain electromagnet draws 3.98 amperes from a 115 volt circuit, what is the resistance?

QUESTIONS AND PROBLEMS (Continued)

7. If a certain electric heater draws 11.5 amperes from a 115 volt circuit, what is the resistance of the heater?
8. Calculate the resistance of a lamp if 0.385 ampere flows through it when connected to 115 volt circuit.
9. What is the resistance of a street car heater which draws 4.9 amperes from a 550 volt line?
10. If a certain electric flatiron draws 4.85 amperes when connected across a 115 volt line, what is its resistance?
11. Compute the hot resistance of a 16 c.p. carbon lamp if it draws 0.48 ampere when connected to a 110 volt lighting circuit.
12. What is the resistance of an electric bell which draws 0.4 ampere when an e.m.f. of 1.2 volts is applied across its terminals?
13. How much current will flow through an incandescent lamp whose hot resistance is 286 Ohms, when connected across a 115 volt lighting circuit?
14. A certain carbon rheostat has a resistance of 0.26 ohm and can safely carry a current of 50 amperes. What is the maximum allowable voltage drop across this rheostat?
15. A 115 volt, 25 watt tungsten lamp has a cold resistance of approximately 40 ohms and a hot resistance of 480 ohms. What current does it take when it is first connected to a 115 volt lighting circuit? At what current does it operate?
16. An ammeter in series with an unknown resistance reads 0.31 ampere, and a voltmeter across the same resistance reads 115.3 volts. What is the unknown resistance?
17. What is meant by electromotive force?
18. A certain flashlight bulb takes 0.48 ampere when an e.m.f. of 2.4 volts is applied across it. Compute its resistance.
19. What is the resistance of an electric toaster which draws amperes from a 115 volt circuit?
20. What is meant by "resistance" in an electric circuit?
21. What is the resistance of an automobile head light which draws 2.5 amperes when connected across a 6 volt battery?
22. What is meant by current?
23. A 60 watt, 120 volt Mazda lamp, having a hot resistance of 240 ohms would draw how much current from a 118 volt circuit?

QUESTIONS AND PROBLEMS (Continued)

24. How much will a voltmeter read if it is connected across a 48 ohm coil through which 0.973 ampere is flowing?

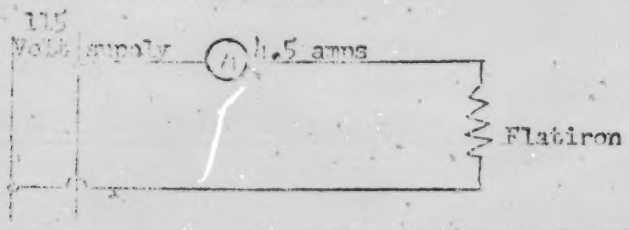
25. A certain 10 amp. ammeter has a resistance of 0.0095 ohm. If this ammeter, through carelessness, were connected directly across a 115 volt line, how much current would tend to flow? What would happen to the ammeter? Do not try it.

26. The current through the field of a certain small dynamo is 2.11 amperes and the voltage applied is 115. What is the resistance of the field?

27. What would happen if a voltmeter were connected in series with a line?

28. A new dry cell has an electromotive force of 1.5 volts and produces 35 amperes when short-circuited. What is the resistance of the cell?

29. After much use, the dry cell in Problem 28 only delivers 6 amperes upon short circuit and has an electromotive force of 1.4 volts, What is the resistance now of this same cell?



30. What is the resistance of the electric flatiron in the circuit shown above?

31. It requires 6.6 amperes to operate the lamps of a series street lighting system. If the resistance of one of these lamps is 7.2 ohms, what voltage is needed to operate this lamp?

32. If there were 200 lamps in the street lighting system in Problem 31, with a total resistance of 1440 ohms, what voltage must be supplied to the circuits?

33. How can the current in any circuit be regulated?

34. With a fixed resistance, how will the strength of the current vary with changes of e.m.f.?

35. With a fixed e.m.f., how will the current vary with different resistances?

36. An electric corn popper has a nichrome heating element whose hot resistance is 19.5 ohms. The maximum allowable current is 6 amps. Could this be used on a 220 volt circuit? What should be the voltage of the circuit?

QUESTIONS AND PROBLEMS (Continued)

37. A heating pad draws 0.35 ampere from a 115 volt line. Compute the resistance of the heating element.

38. A curling iron draws 0.26 ampere from a 115 volt lighting circuit. What is the resistance of the heating element?

39. An electric glue pot used in the carpentry department of a certain trade school can safely carry 2.5 amperes. If the resistance of the heating element is 48 ohms, what voltage-circuit would you operate it on? Why?

40. Suppose the glue pot in Problem 39 would only carry a current of 1 ampere, but has a hot resistance of 220 ohms, what voltage-circuit would you operate this glue pot on? Show all calculations.

41. (a) What would happen if a 115 volt incandescent lamp were connected to a 220 volt power line? Do not try it.

    (b) What would happen if a flashlight bulb were connected to a house lighting circuit? Do Not try it.

42. What would happen if a 220 volt incandescent lamp were connected to a 110 volt circuit? Why? Try it.

43. The resistance of a telephone receiver is 60 ohms. If the current required to operate it is 0.0072 ampere, what voltage must be impressed across the receiver?

44. If the average telegraph relay requires 0.025 ampere for its operation and has a resistance of 200 ohms, what is the voltage drop across the relay?

45. Without the use of your notes or reference books: (a) in your own words, state Ohm's Law, (b) by symbols, give Ohm's Law in its three forms.

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black, 1942	Page 35
Elementary Electricity - Slack 1943	Page 8
Electricity - Burns 1930	Page 40
Lessons in Practical Electricity - Swoope's 1948	Page 127
Elements of Electricity - Timbie 1937	Page 14

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 45
Page 1 of 11

Ohm's Law Applied to Part of a Circuit

PURPOSE:

To be able to apply Ohm's Law correctly to (1) an entire circuit, (2) any part of a circuit.

MATERIALS USED:

One 4 ohm coil, one 6 ohm coil, 3 amp. ammeter, 15 volt voltmeter, short circuiting switch for ammeter, #14 AWG wire, voltmeter leads, storage battery.

PROCEDURE:

Part I.

By the voltmeter-ammeter method (review Exp. 42 of this unit) measure separately the resistance of (a) 6 ohm resistance coil, (b) 4 ohm resistance coil. Record your readings in the Table, Page 2.

CAUTION: DO NOT EXCEED THE MAXIMUM CURRENT THE COILS CAN CARRY WITHOUT OVERHEATING.

Part II.

Connect the resistance coils and the instruments as shown in Figure 1. Have your instructor check your connections before applying any voltage to the circuit.

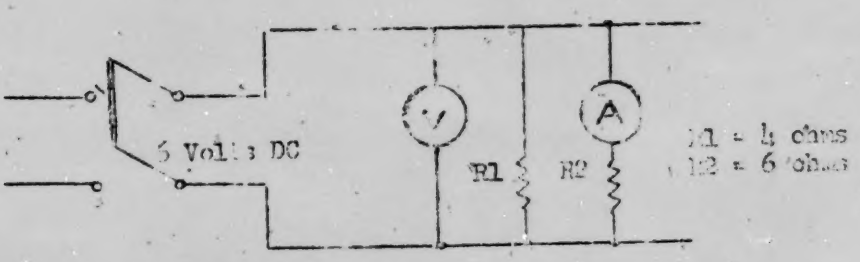


Fig. #1

Close the switch, and read the voltmeter and ammeter. Record your readings in the Table on Page 2.

Part III.

Repeat the experiment with the apparatus connected as shown in Figure 2.

PROCEDURE (Continued)

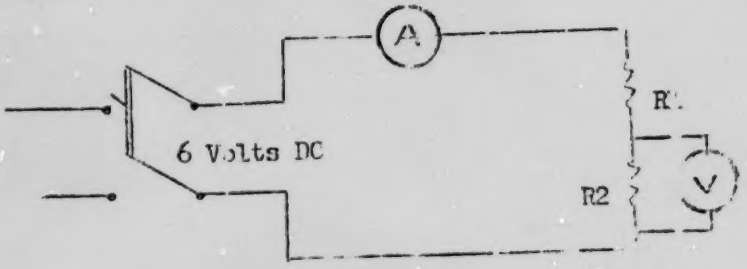


Fig. 2

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TABLE I

Combination	Voltmeter Reading (Volts)	Ammeter Reading (Amps.)	Volt Reading Divided by Ammeter Reading
Resistance of Coil R_1			_____ Ohms
Resistance of Coil R_2			_____ Ohms
Figure 1			_____ Ohms
Figure 2			_____ Ohms

QUESTIONS AND PROBLEMS:

1. For each test, divide the voltmeter reading by the ammeter reading and record in the last column of the above table.
2. Referring to Figure 1:
   (I) Does the ammeter read the line current? Explain. If not, what does it read?
   (II) Does the voltmeter read the voltage across the coil R_2? Explain.
   (III) Does dividing the voltmeter reading by the ammeter reading give (a) the resistance of the parallel circuit, (b) the resistance of coil R_1, or (c) the resistance of coil R_2.
   (IV) Does this prove to you that, when using Ohm's Law, I, E, and R must all be for the same part of the circuit? Explain, basing your reasons on your answers to I, II, and III of this question.
3. Referring to Figure 2:
   (I) Does the ammeter read the current passing through coil R_2? Prove your answer.
   (II) Does the voltmeter read (a) line voltage, (b) the voltage across coil R_1, or (c) the

QUESTIONS AND PROBLEMS (Continued)

voltage across R_2? Prove your answer.

(III) Does dividing the voltmeter reading by the ammeter reading give (a) the resistance of the entire circuit, (b) the resistance of coil R_1, or (c) the resistance of coil R_2?

Prove your answer by readings taken in performing this experiment. (Consult Table on Page 2). Does this prove to you that when using Ohm's Law, I, E, and R must all be for the same part of the circuit? Explain, basing your reasons on your answers to I, II, and III of this question.

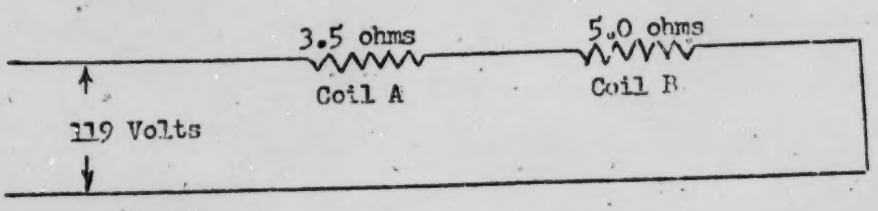
4. Draw a diagram showing how you would connect the instruments to measure the resistance of the entire circuit in (a) Figure 1, (b) Figure 2.

5. What fact have you discovered in this experiment?

EXPLANATORY NOTES:

From your discoveries in this experiment it is evident that, when Ohm's Law is applied to an entire circuit, all three terms I, E, and R must be for the entire circuit. When applying Ohm's Law to part of a circuit, all three terms I, E, and R must be for the same part of the circuit. In other words: (1) The total current (line current) equals the total voltage available to the entire circuit divided by the total resistance of the entire circuit. (2) The current in a certain part of a circuit equals the voltage across the same part divided by the resistance of that same part. A careful study of the sample mind that you cannot divide the voltage across a part of a circuit by the resistance of another part and expect to find the current in the former part.

EXAMPLE:



In the above diagram, you cannot divide 119 by 5 and expect to find the current flowing through the coil B. Why? Neither can you divide 119 by 3.5 and expect to find the current flowing through the coil A. Why?

EXPLANATORY NOTES (Continued)

In using the formula $I = \frac{E}{R}$, $E = I \times R$, and $R = \frac{E}{I}$, you must always remember that all three terms of the equation must be for the same part of the circuit. Ofter the data, as given in a problem, is for different parts of the circuit. In order that I, E, and R all will be for the same part of the circuit, it will often be necessary to apply the Six Laws Governing Series and Parallel Circuits. (Review Exp. F, G, H, I, J and K).

EXAMPLE: Suppose the problem just cited had read: Find the current flowing through coil B.

The first thing to do would be to apply the Law Governing the Resistance of a Series Circuit. Applying this law, the total resistance of the circuit equals 3.5 + 5 = 8.50 ohms.

Knowing the total resistance of the circuit, and the total voltage applied to this circuit, we can find the line current by Ohm's Law.

Line Current - $\frac{\text{Total Voltage Applied to the Circuit}}{\text{Resistance of the Entire Circuit}}$

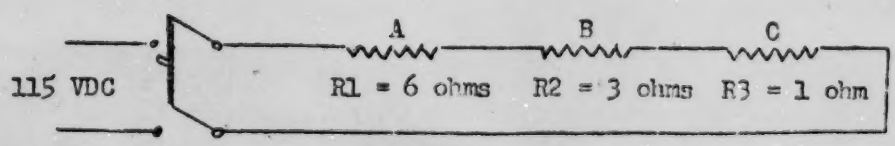
$$I = \frac{E}{R} = \frac{119}{8.5} = 14 \text{ amperes, line current.}$$

The next thing to do is to apply the Law Governing the Current of a Series Circuit, According to this law the current is the same in all parts of a series circuit. Therefore, the current flowing through coil B is 14 amperes. (Ans.)

A careful study of the four sample problems following will make clear to you how to use Ohm's Law correctly.

SAMPLE PROBLEM 1 - In the circuit shown below, find the following

(a) the resistance of the circuit,
(b) the line current,
(c) the voltage drop across A,
(d) the voltage drop across B,
(e) the voltage drop across C.



EXPLANATORY NOTES (Continued)

SOLUTION:

(a) The total resistance of the circuit = $R + R + R = 6 + 3 + 1 = 10$ ohms. (Ans.)

What law does this illustrate?

(b) Line Current = $\frac{\text{Total Voltage Applied to the Circuit}}{\text{Total Resistance of the Circuit}}$

$$I = \frac{E}{R} = \frac{115}{10} = 11.5 \text{ amperes. (Ans.)}$$

NOTE: 115 volts is the total voltage applied to the entire circuit, 10 ohms is the resistance of the entire circuit, and 11.5 amps. is the total current flowing in the circuit. In other words, I, E, and R are all taken for the same part of the circuit.

(c) Voltage across A = Current through A x Resistance of A

$$E = IR = 11.5 \times 6 = 69.0 \text{ volts (Ans.)}$$

Why is the current through "A" 11.5 amperes? What law does this illustrate?

NOTE: The values of the three terms E, I, and R are all for the same part of the circuit.

(d) Voltage across B = Current through B x Resistance of B

$$E = IR = 11.5 \times 3 = 34.5 \text{ volts (Ans.)}$$

Why is the current, passing through "B", 11.5 amperes?

(e) Voltage across C = Current through C x Resistance of C

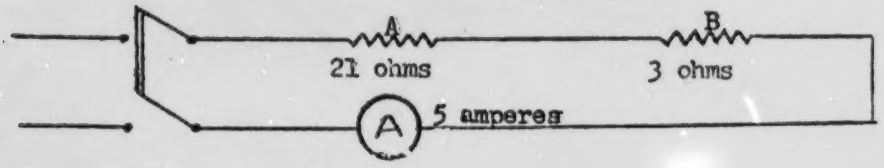
$$E = IR = 11.5 \times 1 = 11.5 \text{ volts (Ans.)}$$

Why is the current, passing through C, 11.5 amperes?

EXPLANATORY NOTES (Continued)

SAMPLE PROBLEM 2 - Find the following in the circuit shown below:

(a) the resistance of the circuit,
(b) the voltage across A,
(c) the voltage across B,
(d) the line voltage.



SOLUTION:

(a) Resistance of entire circuit = 21 + 3 = 24 ohms. (Ans.)

Why is this true?

(b) Voltage across A = Current through A x Resistance of A

E = IR = 5 x 21 = 105 volts (Ans.)

Why is the current through "A" 5 amperes?

(c) Voltage across B = Current through B x Resistance of B

E = IR = 5 x 3 = 15 volts (Ans.)

Why is the current through "B" 5 amperes?

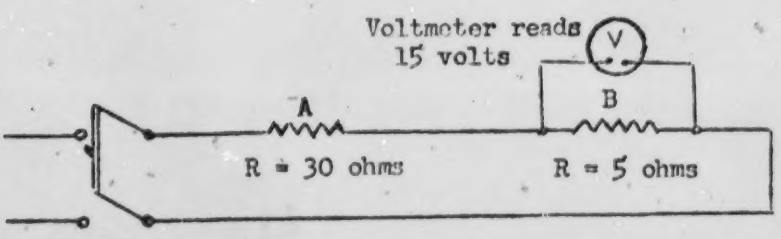
(d) Line Voltage = V_1 V_2

= 105 +15 = 120 volts. (Ans.)

What law does this illustrate?

SAMPLE PROBLEM 3 - Find the following in the circuit shown below:

(a) the line current,
(b) the line voltage,
(c) the voltage across A.



EXPLANATORY NOTES (Continued)

SOLUTION:

(a) Current in B = $\frac{\text{Voltage across B}}{\text{Resistance of B}}$

$$I = \frac{E}{R} = \frac{15}{5} = 3 \text{ amperes}$$

The line current is 3 amperes. (Ans.) Why?

(b) Line Voltage = Line Current x Total Resistance of Circuit

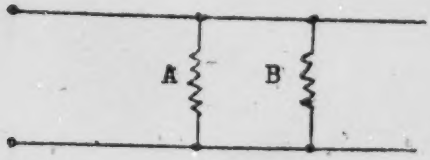
$$E = IR = 3 \times 35 = 105 \text{ volts. (Ans.)}$$

Why is 35 ohms used for the resistance?

(c) Voltage across A = Current through A x Resistance of A

$$E = IR = 3 \times 30 = 90 \text{ volts. (Ans.)}$$

Why is the current through "A" 3 amperes?



SAMPLE PROBLEM 4 - If in the circuit shown above, resistance of A is 200 ohms, resistance of B is 25 ohms, and current through B is 4.5 amperes, what is the current flowing through "A"?

SOLUTION:

Voltage across A = Voltage across B. Why?
Voltage across B = Current through B x Resistance of B

$$E = IR = 4.5 \times 25 = 112.5 \text{ volts,}$$

therefore voltage across A = 112.5 volts.

Current flowing through A = $\frac{\text{Voltage across A}}{\text{Resistance of A}}$

$$I = \frac{E}{R} = \frac{112.5}{200} = 0.5625 \text{ amperes (Ans.)}$$

IMPORTANT:

(1) When Ohm's Law is used, all three terms I, E, and R must be for the same part of the circuit. For example, in sample #4, when the current through "A" was calculated the voltage across "A" and the resistance of "A" were used. In other words, we did not use the voltage

EXPLANATORY NOTES (Continued)

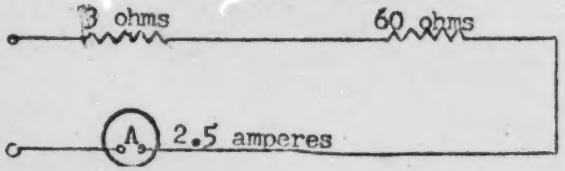
across "A" and the resistance of the entire circuit.

(2) The "Six Laws Governing Series and Parallel Circuits" were heeded in all problems.

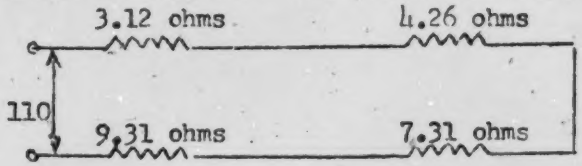
In solving all electrical problems you must observe the conditions outlined in the two preceding paragraphs.

QUESTIONS AND PROBLEMS (Continued)

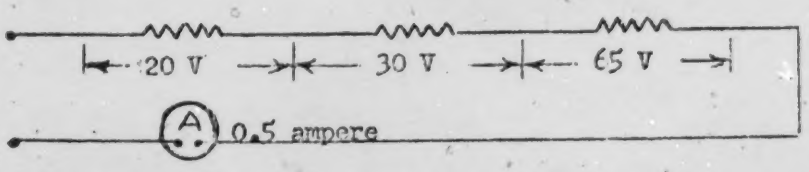
6. Find the line voltage of the circuit shown below:



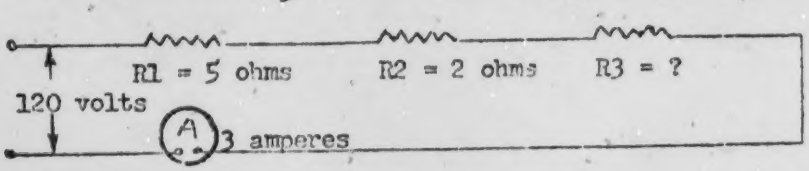
7. Find the line current of the circuit shown below:



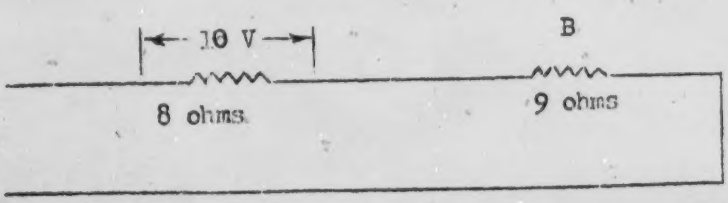
8. Find the resistance of each coil in the following diagram:



9. Find the resistance of R_3 in the following diagram:



10. In the following diagram of a circuit, what is (a) the current flowing through "B", and (b) the line voltage?



QUESTIONS AND PROBLEMS (Continued)

11. An e.m.f. of 115 volts is impressed on a parallel circuit which consists of three branches of 10 ohms, 3.5 ohms and 49.9 ohms respectively.
    (a) What current flows in each branch?
    (b) What is the line current?
    (c) What is the resistance of the circuit?

12. What voltage is needed to send 8 amperes through a circuit consisting of 18 ohms and 14.5 ohms in parallel?

13. What is the resistance of a parallel circuit consisting of three branches 30 ohms, 40 ohms, and 45 ohms respectively?

14. Is it true that in a divided circuit an electric current "always takes the line of least resistance?" Prove your answer by giving an example.

15. Why is a short circuiting switch connected across an ammeter? Explain what it does.

16. How may the total current in a parallel circuit be found if the voltage and individual resistances are known?

17. Four street car heating units each having a resistance of 55 ohms are connected in series. If the trolley voltage is 550 volts, what current flows through the grids?

18. How many 25 watt, 115 volt tungsten lamps, each having a hot resistance of 480 ohms, can be connected in parallel across a 115 volt line without drawing more than 5 amps. from the line?

19. A coffee percolator and a waffle iron each having a hot resistance of 21.5 ohms are plugged in the same duplex receptacle on a 115 volt circuit.
    (a) If the receptacle is rated at 15 amperes, 125 volts, will it stand the current?
    (b) If there is no other load on this circuit, will the branch circuit fuse blow? Show all calculations.
    (c) Which side of a branch circuit is fused?
    (d) What is the maximum rating the N.E.C. allows for the fuse protecting a combination Lighting and Appliance Branch Circuit?
    (e) What is the smallest wire allowable for this type of circuit?

QUESTIONS AND PROBLEMS (Continued)

20. A series street lighting system consists of 120 lamps each having a resistance of 7.1 ohms, and operates on a current of 6.6 amps. If the resistance of the line wires is 105 ohms, what is the voltage supplied to the system? What is the voltage drop across each lamp?

21. Three lamps A, B, C are connected in multiple across a 115 volt lighting circuit. "A" has a hot resistance of 478 ohms, "B" 239 ohms, and "C" 120 ohms. Having the above data, find (a) voltage across each lamp, (b) current through each lamp, (c) line current, (d) resistance of the combination.

22. In a trolley car, five lamps have a hot resistance of 240 ohms each. They are connected in series between the line and track across which the difference of potential is maintained at 550 volts. If four such groups are connected in parallel in a car, what is the joint resistance of the lamp circuit? How much current flows in each lamp? How much current does the lamp circuit draw from the line?

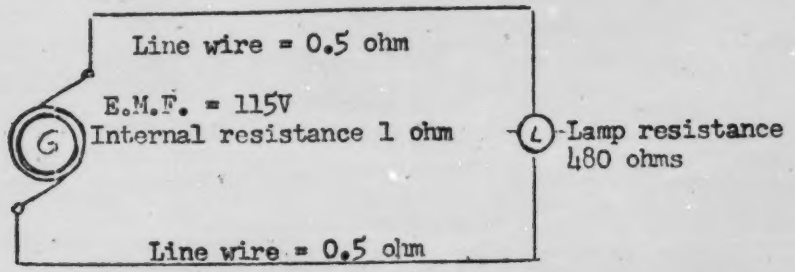
23. How much resistance would you insert in series with a 25 watt, 115 volt tungsten lamp having a hot resistance of 480 ohms to place it across a 220 volt line? HINT--How much current can the lamp safely carry?

24. How large a resistance would you place in series with a 12 ohm bell so that it will draw 0.26 amp. from a 32 volt farm lighting plant?

25. R_1, R_2, R_3 are connected in series.
$R_1 = 64$ ohms, $R_2 = 130$ ohms, $R_3 = 90$ ohms.
The voltage drop across R_3 is 108 volts.
Find the voltage applied to the circuit.

26. Three lamps of 480 ohms, 235 ohms, and one of unknown value are connected in parallel across a 115 volt lighting circuit. The total current drawn by the lamps is 1.5 amperes. Find the value of the unknown resistance. Find the current taken by each lamp.

QUESTIONS AND PROBLEMS (Continued)



27. In the diagram shown above, find (a) the total resistance of the circuit, (b) the current passing through the lamp, (c) the voltage across the lamp, (d) the voltage drop in the two line wires, (e) the voltage drop in the generator.

28. A certain "Dial" decade radio resistance box used for testing purposes consists of resistance coils arranged in equal series groups. In each group there are nine coils in series. There are four groups connected in series in the box which contains coils as follows: first group, nine 1 ohm coils; second group, nine 10 ohm coils; third group, nine 100 ohm coils; fourth group, nine 1000 ohm coils. What is the maximum resistance attainable with this box? Show all calculations.

29. (a) Draw a diagram showing how to measure the resistance of a series circuit by the voltmeter-ammeter method.
(b) Draw a sketch showing how to measure the resistance of a parallel circuit by the voltmeter-ammeter method.

30. How does the fact you discovered in this experiment apply to an ordinary house-lighting circuit? (See Slack - Elementary Electricity, 1st Edition 1931 - Page 21).

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1942	Pages 37-38
Elementary Electricity - Slack 1943	Page 21
Lessons in Practical Electricity - Swoope's 1948	Page 130
Elements of Electricity - Timbie 1937	Page 15.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 46
Page 1 of 3

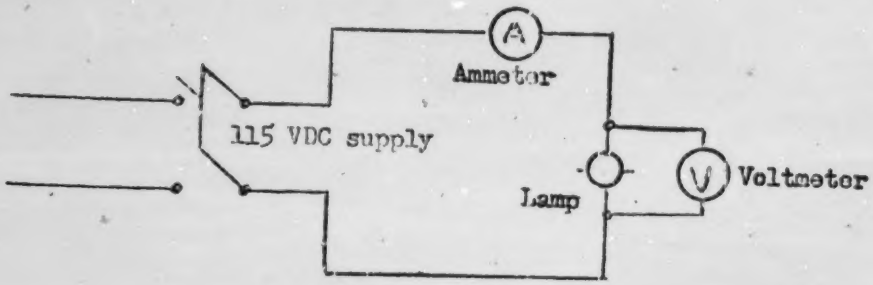
Resistance Measurement: Voltmeter-Ammeter Method

PURPOSE:

To know how to measure resistance by the use of a voltmeter and an ammeter.

MATERIALS USED:

Voltmeter, ammeter, 16 c.p. volt carbon lamp, 25 watt 115 volt incandescent lamp, 50 watt 115 volt incandescent lamp, 100 watt 115 volt incandescent lamp, soldering iron, #14 AWG wire for leads, short circuiting switch for ammeter.



Fig#1

PROCEDURE:

Select an ammeter with proper range and a voltmeter with proper range. A larger capacity ammeter will be needed when measuring the resistance of the soldering iron. Using a 16 c.p. lamp, connect the instruments and lamp as shown in Fig. 1. Close the switch. Record the voltmeter and ammeter readings. Measure the resistance of the lamps and various appliances listed in Table 1. Take at least three sets of readings for each test.

Experiment No. 46
Page 2 of 3

PROCEDURE (Continued)

TABLE I

Lamps	Voltmeter Reading (Volts)	Ammeter Reading (Amperes)	Resistance (Ohms) $R = \frac{E}{I}$
16 c.p.			
25 watt			
50 watt			
100 watt			
Soldering Iron			

QUESTIONS AND PROBLEMS:

1. Compute the value of each unknown resistance from the voltmeter and ammeter readings. Show formula used. Record your answers in the extreme right hand column of Table I.
2. What fact have you learned in this experiment? Of what value to you is this fact?
3. What application of Ohm's Law is made use of in this experiment?
4. In measuring resistance of a waffle-iron by the voltmeter-ammeter method, a 10 ampere ammeter connected in series with the appliance reads 5.12 amperes. A 150 volt voltmeter connected across the appliance reads 115.9 volts. Calculate the resistance of the waffle-iron.
5. The resistance of an automobile head light was measured by the voltmeter-ammeter method. A six volt storage battery was used for the source of power. The voltmeter reads 6.1 volts and the ammeter reads 4.2 amperes. What was the resistance of the lamp?
6. A certain telephone relay operates on a current of 0.12 amperes. To determine whether or not it may be connected directly across a 32 volt circuit, the resistance is measured by the voltmeter-ammeter method. A milliammeter connected

QUESTIONS AND PROBLEMS (Continued)

in series reads 0.03 ampere while the voltmeter reads 6.0 volts. (a) What is the resistance of the relay? (b) May the relay be safely connected to the 32 volt circuit? (c) What is the maximum voltage circuit on which the relay may be used? (d) Where have you used a relay in your signal wiring work?

7. How would you measure the resistance of a Christmas tree lighting outfit while illuminated? Include a sketch in your answer.

8. A certain electric glue pot can safely carry 2.5 amperes. The nameplate was so badly battered that the voltage could not be read. The resistance of the glue pot was measured by the voltmeter-ammeter method. When the test was made, the voltmeter read 116.3 volts and the ammeter read 2.42 amperes. On what voltage circuit should this glue pot be used? Show all calculations.

9. Explain how you would go about it to measure an unknown resistance by the voltmeter-ammeter method.

REFERENCES:

Elements of Electricity - Timbie 1937	Page 78
Elementary Electricity & Magnetism - Jackson & Black 1942	Page 185
Elementary Electricity - Slack 1943	Page 22
Lessons in Practical Electricity - Swoope's 1948	Pages 259-260

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

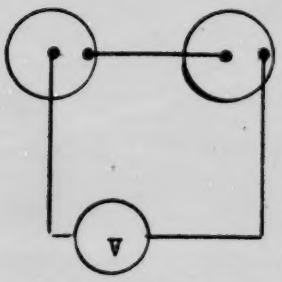
Experiment No. 47
Page 1 of 5

Cells -- Series and Parallel Arrangement

PURPOSE:

(a) To discover whether or not the manner in which cells are connected affects the E.M.F. of the circuit.

(b) To discover which method of connecting cells gives the most current, (1) when the external resistance is high, and (2) when it is low.



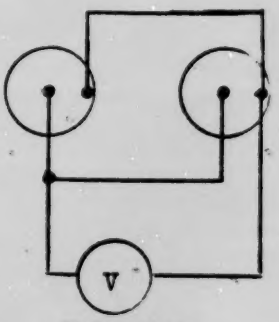
Two cells in series

Fig.#1

Voltmeter

Two cells in parallel

Fig.#2



Voltmeter

PROCEDURE:

Case I: E.M.F.

Connect the zinc electrode of one dry cell to the carbon electrode of the second cell, as shown in Fig. 1. This procedure is termed joining cells in series. Connect the voltmeter to the two remaining terminals. Carefully note and record the reading.

Connect the carbon plates of both dry cells with a wire long enough to reach to the meter. In the same way, connect both zinc plates of the dry cells with a wire long enough to reach to the meter. The two cells are now connected in parallel. Touch the leads to the voltmeter as shown in Fig. 2. Read, and record the readings.

Case II: Current Using Ammeter

(A) External Resistance -- Low One ohm resistor coil
Insert the coil into the circuit of a single cell, as in Fig. 3. Join the connectors (X) with a short piece of #14 copper wire and read the meter. The resistance of the external circuit is the total of the connecting wires, the meter, the resistor, the two-wire connectors, and the short

PROCEDURE (Continued)

piece of #14 copper wire. These are all good conductors (large and short) and, therefore, the total resistance of the external circuit is very small.

Without altering the external circuit (Fig. 3), connect two dry cells in series, as in Fig. 4. Aside from the short piece of wire joining the cells (the resistance of which is megligible), the external circuit is the same as before. Again read the ammeter.

Without altering the external circuit, connect the two dry cells in parallel, Fig. 5. Again the resistance of the external circuit is the same because the resistance of the leads connecting the cells in parallel is negligible. Read the ammeter.

Record all readings in Table I.

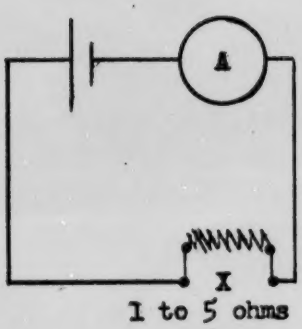


Fig.# 3

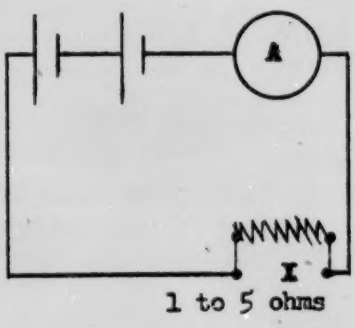


Fig.# 4

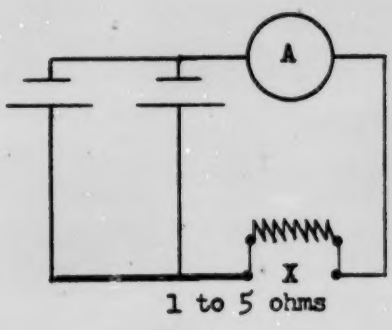


Fig.# 5

(b) External Resistance -- High

Repeat Part A with a 5 ohm resistance coil connected across "X" in Figures 3, 4, and 5.

Record the readings in Table I.

TABLE I

	No. of Cells	How Connected	External Resistance	Ammeter Reading
Case I E.M.F.	1			
	2	Series		
	2	Parallel		
Case II Current	1		Low	
	2	Series	Low	
	2	Parallel	Low	
	1		High	
	2	Series	High	
	2	Parallel	High	

QUESTIONS:

1. (a) Compare the E.M.F. of one cell with two cells in series.

   (b) Compare the E.M.F. of one cell with two cells in parallel.

2. From a study of the Table on this sheet, which arrangement (series or parallel) of the cells seems to give the most current when the external resistance is high, and which when the external resistance is low?

3. If you were installing a door bell circuit and were to use 3 dry cells, would you connect the dry cells in series or parallel? Include a diagram of connections in your answer. Give all reasons for your selection.

4. Carefully explain how to connect cells (a) in series, (b) in parallel. Include sketch in answer.

5. (a) Does a cell have an internal resistance?

   (b) Is the internal resistance of different types of cells the same or different? Prove your answer by citing results obtained in previous experiments.

   (c) Does the resistance of a dry cell change with age?

6. (a) Explain why: Terminal Voltage of a Cell = Induced Voltage (E.M.F.)--Voltage Drop in the Cell.

   (b) If you know the internal resistance of a cell and the current it is delivering, how do you find the drop in the cell?

   (c) Find the terminal voltage of a dry cell when delivering 3 amperes if its E.M.F. is 1.5 volts and its internal resistance is 0.043 ohm.

   (d) Find the terminal voltage of this same dry cell when delivering 6 amperes.

7. (a) When cells are connected in series, what is the E.M.F. of the battery equal to?

   (b) When cells are connected in series, what is the resistance of the battery equal to?

8. (a) What is the total E.M.F. of 3 dry cells connected in series?

   (b) What is the E.M.F. of a circuit consisting of three dry cells in parallel?

QUESTIONS (Continued)

9. (a) What is the resistance of 3 dry cells connected in series if the internal resistances of the cells are 0.05 ohm, 0.04 ohm, and 0.045 ohm respectively?

   (b) Find the combined resistance of these 3 dry cells connected in parallel.

10. (a) Find what current will flow through a circuit consisting of a dry cell whose E.M.F. is 1.5 volts and internal resistance is 0.1 ohm if it is connected to an external resistance of 20 ohms.

    (b) Find what current will flow through the 20 ohm coil if two dry cells, each having an E.M.F. of 1.5 volts and an internal resistance of 0.1 ohm, are in series with the 20 ohm coil.

    (c) What current will flow through the 20 ohm coil if the two dry cells are in parallel?

    (d) What current will flow if the external resistance is 0.1 ohm and one dry cell is used?

    (e) What current will flow through the external resistance of 0.1 ohm if the two dry cells are in series?

    (f) What current will flow through the external resistance of 0.1 ohm if the two dry cells are in parallel?

11. Carefully compare the answers of Problems 8, 9, and 10 with the meter readings you obtained in performing the experiment. Do these three problems illustrate the fact you discovered in this experiment? Explain.

12. Why must the internal resistance of a good cell not be excessive?

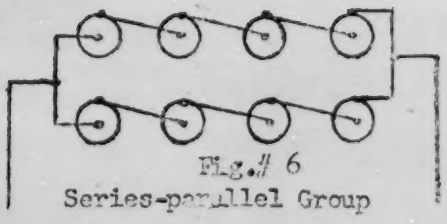


Fig.# 6
Series-parallel Group

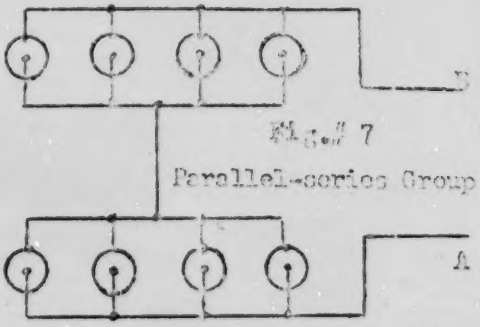


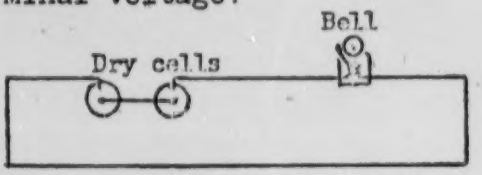
Fig.# 7
Parallel-series Group

QUESTIONS (Continued)

13. (a) Referring to Fig. 6, what is the E.M.F. across "A-B" if the E.M.F. of each cell is 1.5 volts? What is the resistance of the battery if the internal resistance of each cell is 0.05 ohm?

    (b) If the same cells are connected as shown in Fig. 7, what is the E.M.F. across "A-B"? What is the resistance of the battery?

14. What effect, if any, has applying load to the cell upon its terminal voltage?



15. Would the bell ring with the two dry cells connected as shown above? Why?

16. On a certain door bell installation, three dry cells were connected in series having E.M.F. of 1.5 volts, 1.5 volts, and 1.4 volts respectively, and internal resistance of 0.05 ohm, 0.04 ohm, and 0.5 ohm respectively. If the resistance of the external circuit is 20 ohms, what current flows?

17. What is the best arrangement of cells when (a) the external resistance is high, (b) the external resistance is low?

REFERENCES:

Lessons in Practical Electricity - Swoope's	Page 159
Elementary Electricity - Slack	Pages 79-83

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 48
Page 1 of 3

Series & Parallel Circuits: Resistance and Current-Carrying Ability

PURPOSE:

To discover whether or not connecting conductors in series or parallel will affect (a) the resistance of the circuit, (b) the current carrying ability of the circuit.

MATERIALS USED:

Ammeter, dry cell, #28 B. & S. copper wire, #20 B. & S. copper wire, #18 B. & S. copper wire, #16 B. & S. copper wire, #18 B. & S. iron wire, wire gauge, six foot rule.

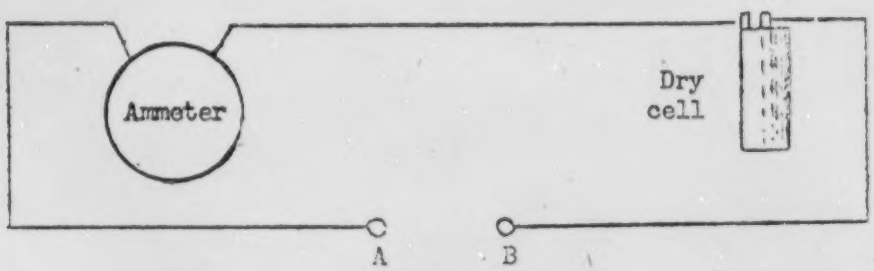


Fig.#1

PROCEDURE:

PART I - SERIES CIRCUIT

Place 25 feet of #28 B. & S. copper wire (coil) in the circuit across the points "a" and "b", Fig. 1. Note and record the reading of the ammeter.

Connect two 25 foot coils of #28 B. & S. copper wire in the series. Touch the free ends across the points "a" and "b". Note and record the reading of the ammeter. Remove both coils from the circuit.

PART II - PARALLEL CIRCUIT

Place one of the 25 foot coils of #28 B. & S. copper wire in the circuit and read the ammeter. Without removing the first coil, place the second 25 foot coil of #28 B. & S. copper wire in parallel with the first coil. Read the ammeter.

Experiment No. 48
Page 2 of 3

PROCEDURE (Continued)

PART III:

Perform the remainder of the operations called for in the table below.

Make a sketch of your connections for the thirteen combinations called for in this table. Label the coils in each sketch.

Trial No.	Connections	Length, Sizes, Material, No. of Coils	Galv. Reading
1	Series	One 25' coil of #28 B. & S. copper	
2	Series	Two 25' coils of #28 B. & S. copper	
3	Parallel	Same coils as above	
4	Series	Three 25' coils of #28 B. & S. copper	
5	Parallel	Same coils as above	
6	Series	Two 25' coils, one 20' coil, and one 5' coil of #28 B. & S. copper	
7	Parallel	Same as above	
8	Series	Two 25' coils of #28, one 20' coils of #28, one 5' coils of #28, and one 5' coil of #16 (all coils copper)	
9	Parallel	Same coils as above	
10	Series	One 25' coil of #28, one 25' coil of #20, and one 25' coil of #16 (all coils copper)	
11	Parallel	Same coils as above	
12	Series	One 30' coil of #18 and one 30' coil of #18 iron	
13	Parallel	Same coils as above	

QUESTIONS:

1. Review. With a fixed e.m.f., does a lower ammeter reading indicate more, or less current flowing in the circuit?
2. Carefully study your meter readings, then answer the following question. Does more, or less current flow when the same conductors are (a) in series, (b) in parallel? Prove your answer by citing meter readings.

QUESTIONS (Continued)

3. Review: With a fixed e.m.f. does a lower ammeter reading indicate more, or less resistance in the circuit?

4. (a) Does placing conductors in series increase or decrease the resistance of the circuit?
   (b) Does placing conductors in parallel increase or decrease the resistance of the circuit? Prove your answers to (a) and (b) by citing ammeter readings.

Fig.#2

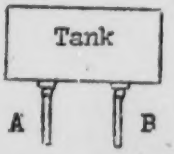


Fig.#3

5. In Fig. 2 and Fig. 3, the tanks are the same size and both are located the same height above the ground. The pipes A and B are the same size and the same length in both Fig. 2 and Fig. 3. In Fig. 3, the pipes are connected in series. Each tank is full of water.
   (a) Which provides the greater number of paths for the water to flow through, the pipes which are in parallel (Fig. 2) or the pipes in series (Fig. 3)?
   (b) Which tank will be emptied first, the one in Fig. 2 or that in Fig. 3? Why?
   (c) Which pipe system (Fig. 2 or Fig. 3) has the greater capacity for carrying water from the tank? Why?

   In other words, which arrangement of pipes would carry the largest quantity of water in a given time?

6. Do series and parallel electric circuits resemble the water analogue in Fig. 2 and Fig. 3? Explain, basing your reasoning on what you saw in this experiment.

7. Remembering what you observed in performing this experiment, compare the current carrying capacity of a series combination made up of three conductors of equal resistance with that of a parallel combination using the same conductors.

8. Compare the current carrying capacity of a series combination made up of three conductors of unequal resistance with that of a parallel combination using the same conductors.

9. State in your own words, what fact you have learned in this experiment.

10. Why must every electrician have knowledge of this fact?

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 49
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Voltage, Current, and Resistance Relations in a Series-Parallel Circuit

PURPOSE:

To study the distribution of current, voltage drops, and resistance in a series-parallel circuit.

MATERIALS USED:

Storage battery; or 6 VDC supply 3 ohm, 4 ohm, and 6 ohm coils; four short circuiting switches; 3 amp. ammeter; 15 volt voltmerer; #14 S.B.R.C. wire for leads.

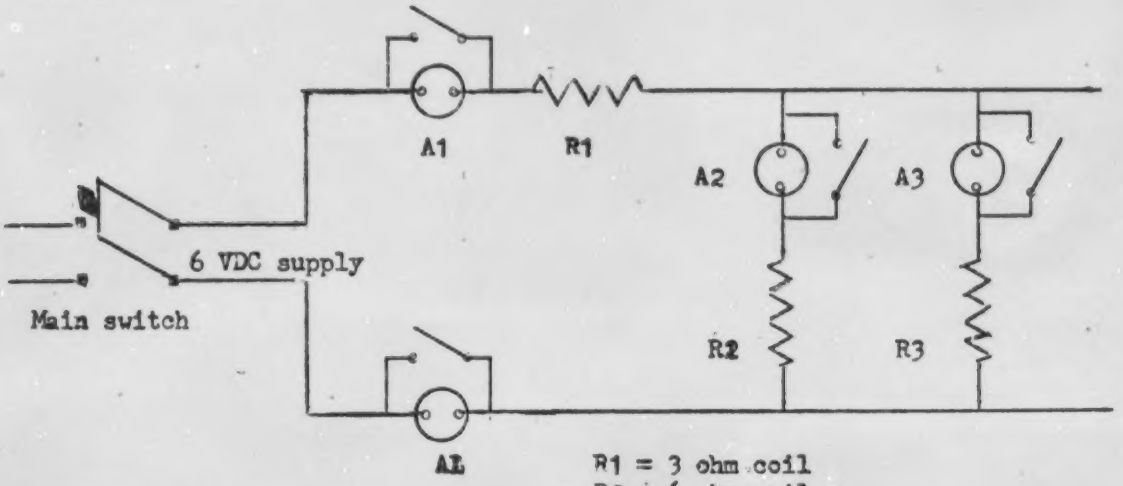


Fig. # 1

PROCEDURE:

By the voltmeter-ammeter method, measure separately the resistances of the following coils: (a) 3 ohm coil, (b) 6 ohm coil, (c) 4 ohm coil. Record in Table I.

Next, connect the coils and instruments as shown in Fig. 1. Have your instructor check your connections before applying any voltage to the circuit.

Then, read the current in each part of the circuit, namely at A1, A2, A3, and AL. (The ammeter is to be shifted to different parts of the circuit by use of the short circuiting switches as described in Exp. F of Unit 4).

PROCEDURE (Continued)

The voltage across the main switch and the voltage across each resistance is to be measured. Record your readings in Table II.

TABLE I

Resistance of Individual Coils			
Coil	Volts	Amps.	Resistance
R_1			_____ Ohms
R_2			_____ Ohms
R_3			_____ Ohms

TABLE II

Voltage, Current and Resistance Relations in a Series-Parallel Circuit

Voltage across R_1 (V_1)	Voltage across R_2 (V_2)	Voltage across R_3 (V_3)	Line Voltage (V_L)	V_1 V_2 Volts	Current Thru R_2 (I_2)	Current Thru R_3 (I_3)	Current Thru R_1 (I_1)	Line Current (I_L)	I_2 I_3 (Amps)	$R = \frac{V_L}{I_L}$ (ohms)	$R_t = R_1 \frac{1}{\frac{1}{R_2} \frac{1}{R_3}}$ (ohms)
#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12

QUESTIONS AND PROBLEMS:

1. Add up the voltage V_1 and V_2 and record in column #5.
2. Add up the currents I_2 - I_3 and record in column #10.
3. Calculate the resistance of the entire circuit by dividing the line voltage by the line current. Record in column #11.
4. Calculate the resistance of the entire circuit and record your answer in column #12. Use the formula given in column #12, Table II, in which R_t is the resistance of the entire circuit, and R_1, R_2, and R_3 are the resistances of the individual coils as recorded in Table I.

CONSULT FIG. 1 AND THE RECORDINGS IN TABLE II AND ANSWER THE FOLLOWING QUESTIONS:

QUESTIONS AND PROBLEMS (Continued)

5. Are the coils R_2 and R_3 in series or in parallel?

6. Is the coil R_1 in series or parallel with the combination made up of coils R_2 and R_3.

7. (a) Do the three laws governing parallel circuits (state each) apply to the combinations made up of R_2 and R_3? Prove your answer by Table II.

   (b) Show how each law applies.

8. (a) Is the current through R_1 the same, or different, than the line current?

   (b) Does the law governing current for a series circuit apply here? Prove your answer.

9. (a) Is, or is not, the line voltage equal to the sum of the voltage drops across R_1 plus the voltage drop across the combination made up of R_2 and R_3?

   (b) Does the law governing voltage for a series circuit apply here? Prove your answer.

10. (a) If you know the joint resistance of the parallel combination (made up of the two resistances R_2 and R_3) and add it to the series resistances $R_1$is, or is not, this answer the resistance of the entire circuit? Why?

    (b) Does the law governing resistance for a series circuit apply here? Prove your answer.

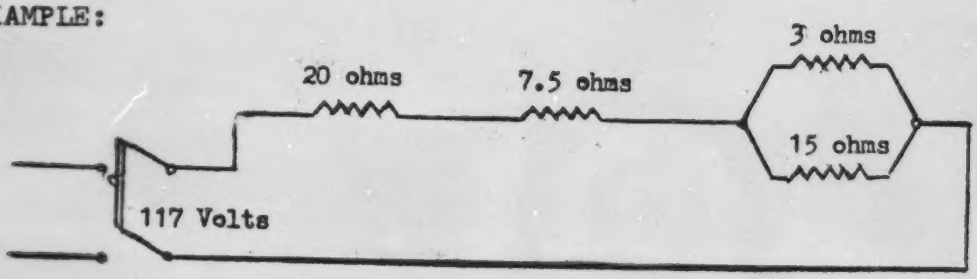
11. Is the following statement <u>true</u> or <u>false</u>?
    When a circuit is made up of a part of the conductors in parallel and part of the conductors in series, as in Fig. 1, to find the resistance of the entire circuit, calculate the joint resistance of the parallel portion of the circuit and then add that to the resistance of the remainder of the circuit which is in series with the branch portion. Prove your answer.

EXPLANATORY NOTES:

In calculating the resistances and voltages of a series-parallel circuit of the type studied in this experiment, it is best to first find the resistance of the parallel combination. This resistance is in series with one or more other resistances. Then, apply the rule for series circuits to find the resistance of the entire circuit. Having the resistance of the entire circuit, and the voltage of the entire circuit being known, the line current can be calculated. Then the current through each part of the circuit may be found.

EXPLANATORY NOTES (Continued)

EXAMPLE:



In the above diagram find:

(a) the resistance of the entire circuit,
(b) the line current,
(c,d,e,f) the voltage drops across the 20 ohm, 7.5 ohm, 3 ohm, 15 ohm coils respectively,
(g,h,i,j) current through the 20 ohm, 7.5 ohm, 3 ohm, 15 ohm coils respectively.

SOLUTION:

(a) Total resistance of the circuit is:

$$20 + 7.5 + \frac{1}{\frac{1}{3} \quad \frac{1}{15}}$$

$$= 20 + 7.5 + \frac{1}{\frac{2}{5}}$$

$$= 20 + 7.5 + 2.5 = 30 \text{ ohms. (Ans.)}$$

(b) The line current = $\dfrac{\text{Total Voltage applied to the Circuit}}{\text{Total Resistance of the Circuit}}$

$$I = \frac{E}{R}$$

$$I = \frac{117}{30} = 3.9 \text{ amps. (Ans.)}$$

(c) Voltage across the 20 ohm coil = Current through 20 ohm coil x the resistance of that coil.

$$E = IR$$

$$E = 3.9 \times 20 = 78 \text{ volts (Ans.)}$$

EXPLANATORY NOTES (Continued)

(d) Voltage across the 7.5 ohm coil = Current through the 7.5 ohm coil x the resistance of that coil.

$$E = IR$$
$$E = 3.9 \times 7.5 = 29.25 \text{ volts (Ans.)}$$

(e) (f) Voltages across the 3 ohm coil and the 15 ohm coil are equal. Why? Voltage across the parallel combination = total current through the combination x the resistance of the combination.

$$E = IR$$
$$E = 3.9 \times 2.5 = 9.74 \text{ Volts. (Ans.}$$

Why is 2.4 substituted for R in the above?

(g) The current through the 20 ohm coil is 3.9 amps. (Ans.) Why?

(h) The current through the 7.5 ohm coil is 3.9 amps. (Ans.) Why?

(i) The current through the 3 ohm coil =

$$\frac{\text{(E) across the 3 ohm coil}}{\text{(R) of that coil}} =$$

$$\frac{9.75}{3} = 3.25 \text{ amps. (Ans.)}$$

(j) The current through the 15 ohm coil =

$$\frac{\text{(E) across the 15 ohm coil}}{\text{(R) of that coil}} =$$

$$\frac{9.75}{15} = 0.65 \text{ amps. (Ans.)}$$

Check:

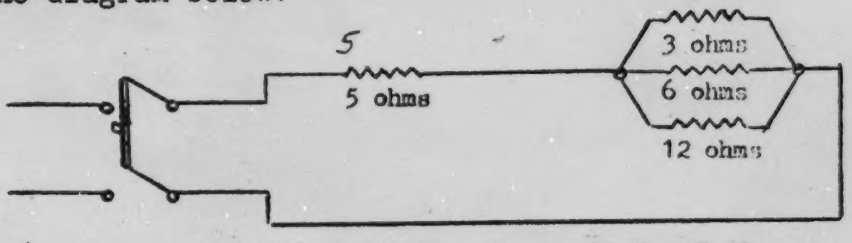
Line voltage = 78 + 29.25 + 9.75 = 117 volts.
Line current = 3.25 + 0.65 = 3.9 amps.
Why is the above a "check" on the problem? What laws are involved in this "check"?

QUESTIONS AND PROBLEMS (Continued)

12. Explain how you would go about solving a series-parallel circuit problem of the type given in this experiment.

QUESTIONS AND PROBLEMS (Continued)

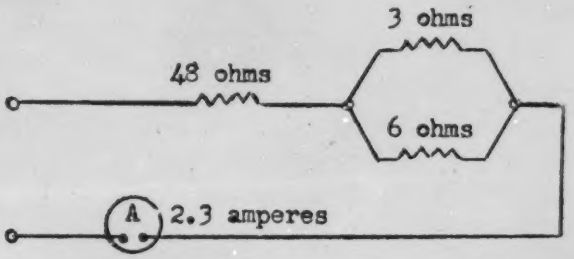
13. What is the resistance of the entire circuit shown in the diagram below?



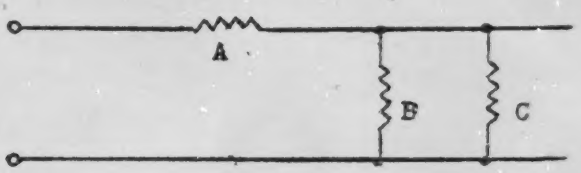
14. If 115 volts are applied across the switch of the circuit, Problem 13, with the switch closed, find (a) the line current, (b) the voltage across each coil, (c) the current through each coil.

15. In the diagram below find:

(a) the drop across the 48 ohm coil.
(b) the voltage across the 3 ohm coil.
(c) the voltage across the 6 ohm coil.
(d) the line voltage.
(e) the current through the 3 ohm coil.
(f) the current through the 6 ohm coil.



16. If, in the circuit diagram below, A = 20 ohms, B = 10 ohms and C = 40 ohms and the current through the resistance B is 3.2 amperes, find (a) the current in each resistance, (b) the line voltage.

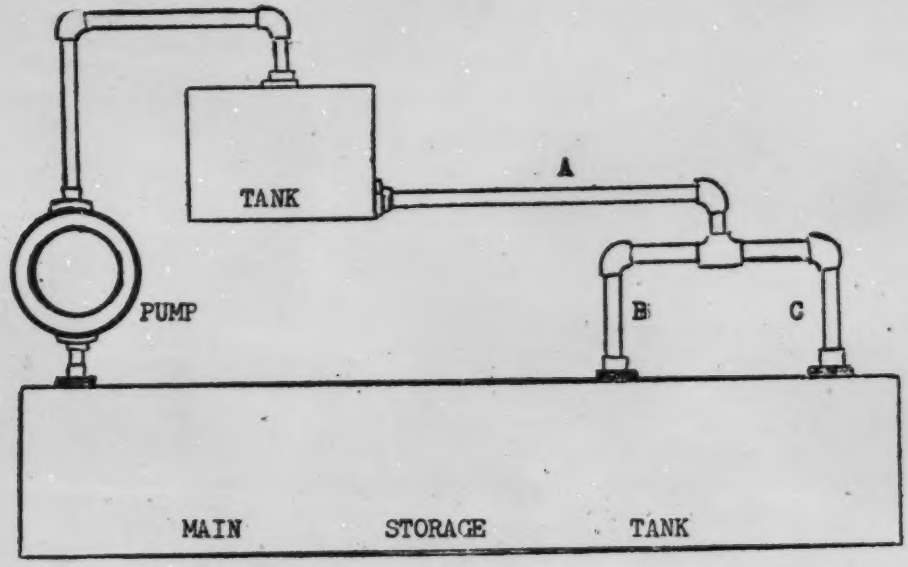


QUESTIONS AND PROBLEMS (Continued)

17. Three tungsten lamps, each having a hot resistance of 480 ohms, are located 100 feet from the cutout. The resistance of each line lead is 0.252 ohm. What is the total resistance of the circuit? If the voltage at the cutout block is 115 volts, find (a) the current flowing through the leads, (b) the current through each lamp, (c) the voltage across each lamp.

18. If a curling iron having a hot resistance of 60 ohms is connected in parallel with the three lamps in Problem 17, calculate, (a) the current flowing through the leads, (b) current through each lamp, (c) current through curling iron, (d) voltage across the parallel combination.

19. Explain in detail how the diagram below illustrates the principles of electrical series-parallel circuits.



20. (a) What fact haveyou discovered in this experiment?
(b) Where will you use this fact in your daily work as an electrician?

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1942 Pages 26-27

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Electrical Experiments

Experiment No. 50
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Electrical Work and Power

As you have already discovered in the Experiment 42, current does not flow through a circuit of its own accord. You discovered that an e.m.f. is necessary to force the current through a circuit.

Furthermore, in the preceding experiment, you discovered that a magneto cannot produce an e.m.f. and send current through a circuit unless it has a supply of energy. You had to work (turn the crank). In other words, you supplied mechanical energy.

Similarly, a dry cell must have a supply of energy. In a dry cell the energy is chemical, and when the supply of chemical energy is used up the cell is "dead".

In future experiments, you will find that in order to produce an e.m.f. and send current through a circuit, you must have a source of energy, which may be either Mechanical, Chemical, Light, or Thermal (heat).

FORCE:

Force is that which produces (or tends to produce) motion or a change of motion.

Example: If an electrician wishes to lift a coil of "B.X." from the sidewalk to his truck, he must apply force. However, force does not always produce motion. Suppose the electrician attempted to lift, by hand, a motor weighing one ton. If he exerted all the force he possessed, the motor would not move.

There are several kinds of force. The force of gravity causes water to run down hill. The force exerted by an electrician in pulling wire into conduit is an example of physical force. A motor driving a grindstone is an example of mechanical force. A mixture of air and vaporized gasoline ignited by an electric spark in the cylinder of a gasoline engine causes an explosion and the piston moves in the cylinder--an example of chemical force.

As you have already discovered in the previous experiments, electromotive force (e.m.f.) is that force which moves or tends to move electricity from one place to another. Just as the rate at which an automobile moves depends upon the force exerted by the engine, so likewise, the rate of flow of electricity depends upon the amount of electromotive force applied.

FORCE (Continued)

These are but a few examples of force.

WORK AND ITS UNITS OF MEASUREMENTS:

The purpose of every machine is to do work.
Work is the overcoming of resistance.

For example, the electrician in lifting the coil of "B.X." performed work. Also, if he had dragged the coil of "B.X." along the sidewalk, he would have done work because he would have overcome resistance (friction). But, in the scientific sense of the word, the electrician would not do any work if he attempted to lift the one ton motor because in failing to move it he would not overcome any resistance.

If a weight of one pound is lifted a vertical distance of one foot, one foot-pound of work is done. If an electrician lifts 40 pounds of wire 2 feet, he does 80 foot-pounds of work. Also, if he pulls hard enough on the 40 pounds of wire to drag it 2 feet he still does 80 foot-pounds of work. In other words -

Work (foot-pounds) = Force (pounds) x Distance (feet)

As was pointed out above, the force exerted may be mechanical, chemical, electrical, etc.; hence the work may be done mechanically, thermally, or electrically but, in all cases, the work may be expressed, if desired, in foot-pounds.

POWER AND ITS UNITS OF MEASUREMENTS:

You must distinguish between the terms "work" and "power". For example, the electrician in lifting the 40 pounds of wire a distance of two feet would do the same amount of work whether he did this in one minute or one hour. But the amount of power required to do it in one hour. Hence, the term "power" adds the element of time. Power means the rate at which work is done.

Perhaps the following simple illustration will help to make clear the difference between Work and Power.

Suppose the basement for a new school building is to be excavated (dug). If one man did this job with a pick and shovel, it would take months. However, a steam shovel could perhaps do the same job in one day. Regardless of whether the man or the steam shovel made the excavation, the total amount of work done in each case would be exactly the same, because in either case, the same amount of gravel and rock must be removed. But the rate of doing the work (power) in the two cases would be far different. The steam shovel is several hundred times more powerful than the man. Hence, it can do the same work faster than the man.

POWER AND ITS UNITS OF MEASUREMENTS (Continued)

A careful study of the above illustration reveals that the total amount of work done is independent of time, that is, the dame work may be performed in one day or one year. But, when we compare the rate at which the work is done, we are considering power. The faster a given job is done, the more power required.

The power required to raise 33,000 pounds one foot in one minute is spoken of as one horse-power. This is the standard unit for expressing mechanical power.

One horse-power (h.p. = 33,000 foot-pounds (ft. lbs.) per minute

$$\text{or } \frac{33{,}000}{60} = 550 \text{ ft. lbs. per second}$$

$$\text{Power} = \frac{\text{Work}}{\text{Time}} = \frac{\text{Foot-pounds}}{\text{Time}}$$

$$\text{Horse-power} = \frac{\text{Foot-pounds per minute}}{33{,}000} = \frac{\text{Foot-pounds per second}}{550}$$

Examples: If a weight of 33,000 pounds is raised 3 feet every minute, the rate of work is 3 h.p. If a weight of 66,000 pounds is raised 2 feet every minute, the rate of work is 4 h.p.

A 25 h.p. motor operated at full load would do:- 33,000 x 25 = 825,000 foot-pounds of work every minute.

ENERGY IS THE CAPACITY FOR DOING WORK:

In order to do work, a person or machine must receive a supply of energy.

Example: A person gets energy from food: a water wheel gets energy from rushing water; a steam turbine gets energy from steam which is produced by burning coal, oil, etc. in a boiler; an automobile gets energy from the gasoline used as a fuel.

SOME OF THE DIFFERENT FORMS OF ENERGY

Chemical Energy	In food, in coal, etc.
Mechanical Energy	Rushing water, moving turbine, etc.
Heat Energy	Steam in turbine, etc.
Electrical Energy	Generator, etc.
Light Energy	Sun, lamps, etc.

POWER AND ITS UNITS OF MEASUREMENTS (Continued)

There is a fixed amount of energy in the universe at all times. Energy cannot be created nor destroyed. However, it can be, and often is, changed from one form to another.

Example: Coal, (chemical energy) is burned up in a boiler to produce steam (heat energy) to run a turbine. The turbine (mechanical energy) drives a generator giving out electrical energy. The generator runs motors (mechanical energy), heats conductors (heat energy), lights lamps (light energy), plate metals (chemical energy), etc.

ELECTRICAL POWER -- WATT, KILOWATT:

Just as mechanical power is the rate at which mechanical energy is expended, and is independent of the total work to be performed, so electrical power is the rate at which electrical energy is expended and is independent of the total amount of electrical energy consumed.

You have already discovered that when current is sent through a high resistance wire, the wire becomes hot. The wire (resistance) takes in electrical energy and gives out heat. In other words, electrical energy is being supplied at a certain rate and the rate at which this electrical energy is being supplied is called electrical power.

FIG. # 1

Example: 240 gallons (2000 pounds) of water flow each second over the waterfall (Fig. 1) which is 20 feet high. The water rushing over this waterfall has the capacity of doing work, (turning water wheel). The power of the water is 2000 x 20 = 40,000 foot-pounds per second.

Since Horse-power = $\frac{\text{Foot-pounds per second}}{550}$

The power available is: $\frac{40,000}{550}$ = 72.7 h.p. (Ans.)

ELECTRICAL POWER: WATT, KILOWATT (Continued)

The above illustration shows that in order to measure water power we must know two things, (a) the quantity (in pounds) of water flowing per second, and (b) the "head" of the water.

"Head" of water means the pressure due to the weight of the column of water and is dependent upon its height.

COMPARISON OF WATER AND ELECTRIC POWER

Consult the table given on Sheet , of the Inf. Lesson A in Unit I of Block XII. There, we learn that "head" in water system corresponds to volts in an electric system. We also learn that quantity per second in water system corresponds to amperes in an electric system.

Therefore, if in a water system:

Water-power = Quantity of water per second x Head

or, Foot-pounds per second = Pounds per second x feet,

or, Horse-power (h.p.) = $\frac{\text{Pounds per second x feet}}{550}$

It follows that to measure electrical power (watts), we must multiply the quantity of electricity flowing per second (current in amperes) by the electromotive force (volts).

Electric Power (watts) = Amperes x Volts

Following, is a comparative summary of water and electrical power.

(Water Power / Electric Power) in (Foot-pounds per second / Watts) equals quantity of

(water / electricity) flowing per second (gallons (pounds) per second / current in amperes)

multiplied by motive force ("feet of head" / volts).

The unit of electric power is called a watt. Therefore, just as mechanical power is measured in foot-pounds per second, electrical power is measured in watts.

In fact, mechanical power can be converted into electrical power for:

1 watt = .074 foot-pound per second

COMPARISON OF WATER AND ELECTRIC POWER (Continued)

A watt is the power needed to keep a current of one ampere flowing under a drop of one volt.

POWER FORMULAS

Watts (P) = Amperes (I) x Volts (E)

$$P = IE$$

Since the Watt is a very small unit of power, the Kilowatt (1,000 watts) is more often used.

$$\text{Kilowatts} = \frac{\text{Amperes} \times \text{Volts}}{1000}$$

It is often necessary to convert mechanical power (H.P.) into electrical power (Watts and Kilowatts).

For example: Electric motors are rated in horse-power while generators are rated in Kilowatts.

By experiment, it has been found that

1 horse-power = 0.746 kilowatts = 746 watts
1 kilowatt = 1.34 horse-power

Example #1: Change 7.5 K.W. to horse-power
H.P. = 7.5 x 1.34 = 10 h.p. (Ans.)

Example #2: Change 30 h.p. to K.W.
K.W. = 30 x 0.746 = 22.4 K.W. (Ans.)

Example #3: If a lamp draws 0.24 ampere from a 115 volt line, at watt rate is it using power?
P = I E
P = 0.24 x 115 = 27.6 watts (Ans.)

Example #4: If an electric range is drawing 40 amperes from a 230 volt line, at what rate is it using power?

$$\text{K.W.} = \frac{\text{Amperes} \times \text{Volts}}{1000} = \frac{40 \times 230}{1000} = 9.2 \text{ K.W. (Ans.)}$$

Example #5: To find the Current When the Power and Voltage are known. What current does a 50 watt lamp draw from a 115 volt lighting circuit?

$$I = \frac{P}{E} = \frac{50}{115} = 0.435 \text{ amp. (Ans.)}$$

Example #6: To Find the Voltage When the Power and Current are Known. A 660 watt flatiron requires a current of 6 amperes to operate satisfactorily. On what voltage circuit should it be used?

$$E = \frac{P}{I} = \frac{660}{6} = 110 \text{ volts. (Ans.)}$$

POWER USED TO OVERCOME RESISTANCE:

(A) $P = I E$

By Ohm's Law $E = I R$
Substituting I R for E in formula "A"
$P = I \times I \times$ or

(B) $P = I^2R$

Example: Find the power loss in the wires of a line 50 feet long (100 feet of wire) when 20 amperes is flowing. The line wires are #10 B & S Copper (0.1 ohm resistance.)

$P = I^2R$

$P = (20)^2\ 0.1 = 400 \times 0.1 = 40$ watts. (Ans.)

Again, $P = I E$
By Ohm's Law $I = \frac{E}{R}$

Substituting $\frac{E}{R}$ for I in the above formula:

$P = \frac{E}{R} \times E$

or (C) $P = \frac{E^2}{R}$

Example: The resistance of 150 volt D.C. voltmeter is 15,000 ohms. What power is used by this voltmeter when it is connected across a 115 volt circuit?

$P = \frac{E^2}{R}$ (formula C)

$P = \frac{(115^2)}{15{,}000} = \frac{13{,}225}{14{,}000} = 0.88$ watt. (Ans.)

Equation "A" is useful when the current and voltage are known.

Equation "B" is useful when the current and resistance are known.

Equation "C" is useful when the voltage and resistance are known.

ELECTRICAL WORK OR ENERGY - JOULE AND KILOWATT-HOUR:

Electrical power (watt or kilowatt) tells the rate at which electrical energy is being consumed, but it dies not tell the total amount of work done (the total amount of electrical energy expended). The total work done (electrical energy) is equal to electrical power multiplied by time. The unit of electrical work (energy) is the watt-second or joule. One joule is the amount of work performed by a current of one

ELECTRICAL WORK OR ENERGY - JOULE AND KILOWATT-HOUR (Continued)

ampere flowing for one second under a drop of one volt.

Total Electrical Work (Energy) Done = Electrical Power x Time
Joule = Amperes x Volts x Seconds

or $W = IEt$
in which: W is the electrical energy in joules
I is the current in amperes
E is the voltage
t is the time in seconds

However, the watt-second (joule) is ordinarily too small a unit for commercial purposes. Therefore, a larger unit, the Kilowatt-hour (Kw-hr) is commonly used.

Kilowatt-hour = Kilowatts x hours.

Example #1: Find the electrical energy consumed by an electric range which draws 35 amperes from a 230 volt line for two hours.

$$\text{Kilowatt-hours} = \frac{I \times E}{1000} \times \text{hours}$$

$$= \frac{35 \times 230}{1000} \times 2$$

= 16.1 Kw. hrs. (Ans.)

Example #2: Find the cost of operating the above electric range for 2 hours if the rate is 3 1/2¢ per kilowatt hour.

Cost = Kilowatt-hours x Price per Kilowatt-hour
= 16.1 x \$0.035 = \$0.564 (Ans.)

SUMMARY:

Work is the overcoming of resistance.
Work (foot-pounds) = Force (pounds) x Distance (Feet).
Power is the rate of doing work.

Electrical Power (Watts) $= I \times E = I^2 \times R = \frac{E^2}{R}$

Electrical Power (Kilowatts) $= \frac{I \times E}{1000} = \frac{I^2 \times R}{1000} = \frac{E^2}{R \times 1000}$

Watt is the unit of power,
1 Kilowatt = 1000 watts.
1 horse-power = 33,000 ft. lbs. per minute = 550 ft. lbs. per second.
1 H.P. = 746 watts = 0.746 kilowatts.
1 Kilowatt = 1.34 horse-power.

SUMMARY (Continued)

Energy is the capacity for doing work.
Electrical Energy is measured commercially in kilowatt-hours.
Electrical Energy = Electrical Power x Time.

$$\text{Kilowatt-hour} = \text{Kilowatt} \times \text{Hours} = \frac{\text{Watts}}{1000} \times \text{Hours}.$$

QUESTIONS AND PROBLEMS:

1. What is (a) force? (b) work? (c) power? (d) energy? (e) What is the difference between power and work?
2. Give an example where force is exerted by technically no "work" is done
3. At all times an e.m.f. exists between the terminals of a battery tending to send a current of electricity from one terminal to the other through the air. However, this e.m.f. is not sufficient to overcome the resistance of the air and as a result no current flows, In the external circuit, is the battery doing work? Explain.
4. Suppose an electric bell is connected across the terminals battery doing work? Why?
5. What is the unit of measurement for, (a) mechanical work, (b) electrical work, (c) mechanical power, (d) electrical power? (e) What is the difference between a kilowatt and a kilowatt-hour? Explain in detail.
6. Are either or both of the following statements true? Explain.
   (a) "Electricity is sold for so many cents per kilowatt".
   (b) "Electrical energy is sold for so many cents per kilowatt-hour".
7. What unit is used in rating the capacity of (a) an automobile gas engine, (b) an electric light, (c) an electric toaster, (d) an electric range, (e) an electric motor, (f) an electric generator.
8. Fill in the following blanks:

1 watt	= _____	foot-pounds per second.
1 horse-power	= _____	foot-pounds per minute.
1 horse-power	= _____	foot-pounds per second.
1 kilowatt	= _____	watts.
1 kilowatt	= _____	horse-power.
1 H.P.	= _____	K.W.
1 joule	= _____	watt seconds.
1 kilowatt-hour	= _____	watt seconds.
1 kilowatt-hour	= _____	watt hours.

QUESTIONS AND PROBLEMS (Continued)

9. (a) What electrical power is required to operate a 50 watt lamp?
   (b) What electrical energy is expended in operating a 50 watt lamp for 5 hours?
   (c) What would it cost to operate a 50 watt lamp for 5 hours if the rate is 6¢ per kilowatt-hour?

10. (a) Change 746 watts to kilowatts.
    (b) Express 5 horse-power in kilowatts.
    (c) Change 7.5 K.W. to h.p.

11. What power is used by an electric heater which draws 3.8 ampere from a 115 volt line?

12. What power is required to operate a flashlight bulb which takes 0.48 ampere when an e.m.f. of 2.4 volts is applied across it?

13. What power is needed to operate a 5.5 ohm door-bell requiring 0.5 ampere?

14. What power is needed for an electric toaster which draws 4 amperes from a 115 volt circuit?

15. What current does a 50 watt, 115 volt lamp draw from a lighting circuit whose voltage is 118 volts?

16. What current does a 660 watt flatiron draw from a 115 volt circuit?

17. (a) Five 100 watt lamps are connected in parallel to a circuit. What power is required?
    (b) Five 100 watt lamps are connected in series in a street car. What power is required?

18. What is the resistance of a 660 watt, 115 volt waffle iron?

19. What current is drawn from the line by five 50 watt, 115 volt lamps connected in parallel?

20. How much electrical energy is consumed by a 40 watt lamp burning for 24 hours?

21. How much energy is lost in line leads with resistance of 0.2 ohm and which carry a current of 600 amperes for 24 hours?

22. Find the total cost of operating each of the following appliances for 4 hours at 5 cents per kilowatt-hour: two 660 watt heaters, forty 50 watt lamps, twenty 60 watt lamps.

CONSULT YOUR CODE BOOK, AND ANSWER THE FOLLOWING:

23. What is an <u>outlet</u>? May an outlet contain more than one socket?

QUESTIONS AND PROBLEMS (Continued)

24. What is a 15-Ampere Branch Circuit?
    (a) What is the smallest size wire that may be used for a 15-Ampere Branch Circuit?
    (b) What is the largest size fuse permissible for a 15-Ampere Branch Circuit?
    (c) What is the largest size (a) portable electrical appliance (in watts) (b) fixed appliance allowed on a 15-Ampere Branch Circuit?
25. (a) Answer "a", "b", and "d" of Question 24 for a 20 ampere Branch Circuit.
    (b) What is the rating of the receptacles used on those circuits?
26. May two 1700 watt appliances be placed on a 15-Ampere Branch Circuit? Explain.
27. Give the power ratings of the following types of sockets:

Class	Key (Watts)	Keyless (Watts)
Candelabra	_____	_____
Medium	_____	_____
Mogul	_____	_____

28. What current does ten 100 watt lamps draw? May they be put on one circuit? If so, what size fuses should be used?
29. Which has the greater resistance - a 50 watt, 115 volt lamp or a 100 watt, 115 volt lamp? Which draws the greater current? Show calculations.

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1942 — Chapter III
Elementary Electricity - Slack 1943 — Chapter VII
Lessons in Practical Electricity - Swoope's 1948 — Lesson IX
Elements of Electricity - Timbie 1937 — Chapter II
National Electric Code

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 51
Page 1 of 2

Resistance - Material

PURPOSE:

To discover what effect, if any, the material of a conductor has upon its resistance.

MATERIALS USED:

Dry cell, Ammeter, #18 B. & S. copper wire, #18 B. & S. iron wire, #18 B. & S. aluminum wire, #18 B. & S. manganin wire.

PROCEDURE:

In this experiment wires of the same size, equal length, but of different materials are to be used.

Repeat Experiment A, using 50 foot lengths of #18 B. & S. wire of the materials called for in Table III. Make a sketch of your connections.

TABLE III

Materials	Cross Section (By number)	Length	Ammeter Reading
Copper	#18 B. & S.	50 ft.	
Iron	#18 B. & S.	50 ft.	
Aluminum	#18 B. & S.	50 ft.	
Manganin	#18 B. & S.	50 ft.	

QUESTIONS:

1. Did the ammeter show the same deflection when wires of different materials were inserted in the circuit? Explain.
2. With a fixed e.m.f. does the same current flow with the wires of different materials? Explain.
3. What effect, if any, does the material of a conductor have upon the resistance of a conductor? Explain, basing your conclusions on what you have observed in performing this experiment.
4. How will knowledge of the fact you have discovered in this experiment help you in your electrical work? Explain.

SUPPLEMENTAL QUESTIONS:

1. What factors (so far as you have discovered) affect the resistanee of a conductor?

Experiment No. 51
Page 2 of 2

SUPPLEMENTAL QUESTIONS (Continued)

2. (a) What effect has the length upon the resistance of a conductor?
   (b) What effect has the cross-section upon the resistance of a conductor?
   (c) What effect has the material upon the resistance of a conductor?
3. If a coil wound with 2500 turns of #24 B. & S. copper wire has 1200 turns removed, is the resistance increased or decreased? Explain.
4. Which has the greater cross-section (a) #18 B. & S. wire or #24 B. & S.. (b) #14 B. & S. or #1 B. & S. wire?
5. Which will have the greater resistance, a coil wound with 2500 turns of #24 B. & S. copper wire or one wound with 2500 turns of #18 B. & S. Copper wire? Explain.
6. Which will have the greater resistance, a mile of #14 B. & S. iron wire or a mile of #14 B. & S. copper wire? Explain.
7. An electrician installing a convenience outlet in a kitchen uses a piece of twin #14 B.X. 25 ft. long. In the parlor, installing a ceiling outlet, he uses a piece of twin #14 B.S. 15 ft. long. Which piece of B.X. had the greater resistance? Explain
8. In calibrating instruments in factory laboratories, the resistance of a low resistance coil is sometimes increased slightly by stretching the wire a little. Explain in detail how stretching the wire may slightly increase the resistance of a wire.
9. Why is not iron wire used more in the electrical industry? Give examples where iron wire is used.

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 52
Page 1 of 3

Resistance-Length

PURPOSE:

To discover what effect, if any, the length of a conductor has upon its resistance.

DEFINITION:

Resistance is the opposition offered by a conductor to the flow of electricity through it.

MATERIALS USED:

Dry cell, ammeter, #28 B. & S. copper wire.

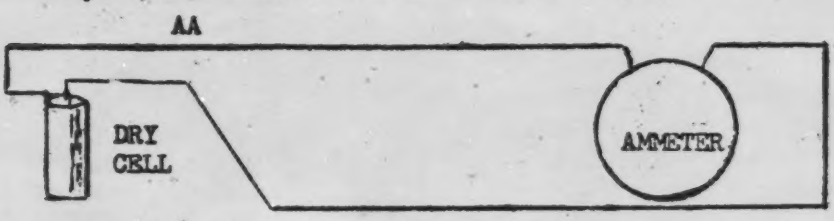

FIG # 1

PROCEDURE:

Cut off a piece of #28 B. & S. copper wire five feet long. This is represented by the wire "AA" in Fig. 1. Use a short piece of #28 B. & S. copper wire for the other ammeter lead.

Touch the wire "AA" to the terminal of the dry cell. Note and record the reading on the ammeter.

Repeat, using the various lengths of #28 B. & S. copper called for in Table I.

TABLE I

Length	Cross Section (By number)	Material	Ammeter Reading
5 ft.	#28 B. & S.	Copper	
10 ft.	#28 B. & S.	Copper	
25 ft.	#28 B. & S.	Copper	
50 ft.	#28 B. & S.	Copper	
100 ft.	#28 B. & S.	Copper	

QUESTIONS:

1. Did the ammeter show the same current when various lengths of wire were inserted in the circuit? Explain.

QUESTIONS (Continued)

2. With a constant e.m.f., does the same current flow with different lengths of wire in the circuit? Explain. (Note--The larger the current, the greater is the deflection of the needle on the meter).

3. Explain, in your own words, what the following statement means to you: "Resistance is the opposition offered to the flow of electricity through a conductor".

4. Since resistance opposes the flow of electricity in a circuit, it is evident that the greater the resistance (opposition) the less will be the current flowing through the conductor. Bearing this in mind (and also remembering that the amount the ammeter deflects depends upon the strength of the current) answer the following questions in detail: (a) Does increasing the length of a wire increase or decrease its resistance? (b) Does decreasing the length of wire increase or decrease its resistance?

   Prove your answers by citing ammeter readings.

5. How will knowledge of the fact you have discovered in this experiment help you in your electrical work? Explain.

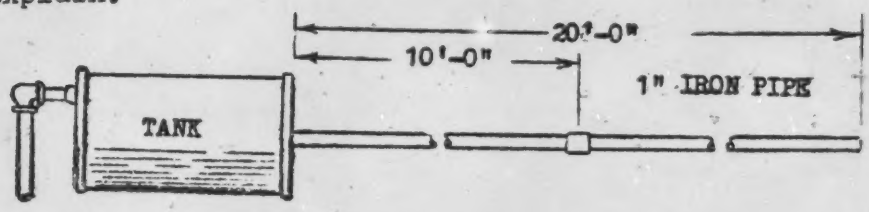

FIG # 2

The water in the tank (Fig. 2) is maintained by a pump at a constant pressure. Due to friction the wall of the pipe offers an opposition or resistance to the flow of water through it.

Imagine that the pipe line at the start is 10 feet long. Later the length of the pipe line is made 20 feet. (Same size and kind of pipe). It is evident that the 20 ft. pipe would have twice as much friction as the 10 ft. pipe for the water having passed through the first 10 ft. would then have to go on through the other 10 ft. Therefore, the 20 ft. pipe offers twice as much opposition (resistance) to the flow of water through it.

QUESTIONS (Continued)

6. In what ways do the electric circuits in this experiment resemble the water analogy given in Fig. 2? Are the results produced in each, in any way similar? Explain.

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1933 — Page 8
Electricity - Burns 1930 — Page 38
Lessons in Practical Electricity - Swoope's 1926 — Page 54

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Experiment No. 53
Page 1 of 2

Resistance - Cross Section

PURPOSE:

To discover what effect, if any, the size (cross-sectional area) of a conductor has upon its resistance.

MATERIALS USED:

Dry cell, ammeter, #28 B. & S. copper wire, #24 B. & S. copper wire, #18 B. & S. copper wire, wire gauge.

PROCEDURE:

Connect the apparatus the same as in Experiment 52 (make a sketch of your connections).

In this experiment, wires of the same material, of equal lengths, but of different cross-sectional areas, are to be used.

Carefully examine each wire and note the difference in cross-sectional area.

TABLE II

Cross Section (By number)	Length	Material	Ammeter Reading
#28 B. & S.	25 ft.	Copper	
#24 B. & S.	25 ft.	Copper	
#18 B. & S.	25 ft.	Copper	

QUESTIONS:

1. Did the ammeter show the same current readings when various sizes of wire were inserted in the circuit? Explain.
2. With a constant e.m.f., does the same current flow with wires of different cross-sectional areas? Explain.
3. What effect, if any, does cross-sectional area have upon the resistance of a conductor? Explain in detail, basing your reasons on what you observed in performing this experiment.

Experiment No. 53
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QUESTIONS (Continued)

4. How will knowledge of the fact you have discovered in this experiment help you in your electrical work? Explain.

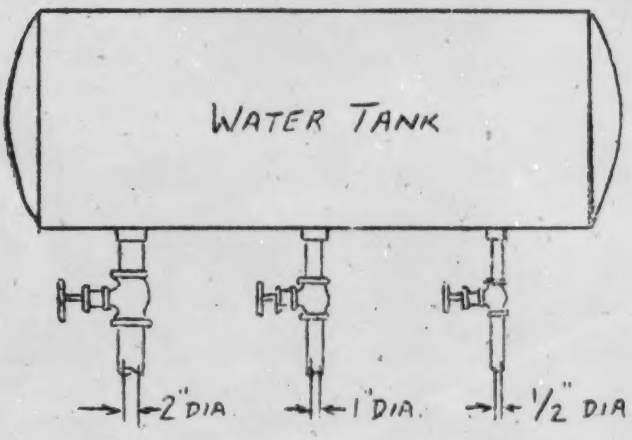

FIG. 1.

5. In Fig. 1, each pipe is provided with a valve. Only one valve is opened at a time.
   (a) Which pipe working alone could empty the tank quickest?
   (b) Which pipe working alone would require the longest time to empty the tank? For a given length and kind of pipe, does changing the cross-sectional area affect the resistance to the flow of water through it? Explain.

6. In what respects do the electric circuits in this experiment resemble the water analogy given in Fig. 1? Are the results produced in each in any way similar? Explain.

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Experiment No. 54
Page 1 of 1.

Resistance-Shape

PURPOSE:

To discover what effect, if any, the shape of a conductor has upon its resistance.

MATERIALS USED:

Dry cell, ammeter, #24 E.S.C.C. round magnet wire.

PROCEDURE:

Repeat Experiment 52 by inserting a 25 ft. length of #24 E.S.C.C. round magnet wire in the circuit. (Make a sketch of your connections). Note and record the ammeter readings.

Remove the wire from the circuit. Wind it in the form of a coil of several turns. Be careful not to bend or stretch the wire in such a manner as to change its length or cross-section. Insert the coil in the circuit. Note and record the ammeter reading.

Remove the coil from the circuit. Make it a straight piece of wire. Rewind in the form of a rectangle with several turns. Be careful not to stretch or bend the wire in such a manner as to change its length or cross-section. Insert in the circuit. Note and record the ammeter reading.

TABLE IV

Shape	Length	Cross-Section (By number)	Material	Ammeter Reading
Straight	25 ft.	#24 B. & S.	Copper	
Coil	25 ft.	#24 B. & S.	Copper	
Rectangle	25 ft.	#24 B. & S.	Copper	

QUESTIONS:

1. Did the ammeter show the same deflections when the same conductor, but made in various shapes, was inserted in the circuit? Explain.
2. With fixed e.m.f., does the same current flow when a given wire is bent in different shapes? Explain.
3. What effect, if any, does the shape of a conductor have upon the resistance of that conductor? Explain, basing your conclusions on what you observed in performing this experiment.

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Experiment No. 55
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Calculating Resistance by $R = \frac{KL}{D2}$

PURPOSE:

To calculate the resistance of conductors by using the formula

$$R = \frac{KL}{D2}$$

MATERIALS USED:

Micrometer, wire gauge, Wheatstone bridge, wire measuring reel (or steel tape), various sizes and kinds of wire.

EXPLANATORY NOTES, PROBLEMS, AND QUESTIONS:

Review Questions: What effect does (a) length, (b) cross-sectional area, and (c) kind of material, have upon the resistance of a conductor?

Specific Resistance or Resistivity

From the three facts brought out in the above question, the following rule for resistance may be stated:

"The resistance of a body of uniform cross-section varies directly as its length, and inversely as its cross-sectional area".

That is:

$$R = \frac{K\,L}{A}$$

where R is the resistance,
L is the length,
A is the area at right angles to the current flow,
and K is a constant of the material known as the specific resistance or resistivity of the substance.

For a given temperature, K is the resistance of a conductor of a given material having a unit length and cross-sectional area. K will depend upon: (1) the material, (2) the unit of length selected, (3) the unit of cross-sectional area selected, (4) the temperature of the conductor. Therefore, in order to calculate the resistance of a wire, it is necessary to know the resistance of a piece having a unit length and a unit cross-sectional area. When the electrician uses this formula, he usually uses feet for the length (L) and circular mils for the area (A).

EXPLANATORY NOTES, PROBLEMS, AND QUESTIONS (Continued)

If these units of length and area are used, the constant K will have to be the resistance of a wire one foot long and one circular mil in cross-sectional area. Hence, it is obvious that, in order to use this formula intelligently, you must have a working knowledge of such terms as circular mils, circular mil-feet, etc. These are explained in the paragraphs following.

The Circular Mil

In wire tables the circular mil is the standard unit for cross-section. (See N.E.C. Table on Allowable Carrying Capacities of Wires).

The third column of this table gives the cross-sectional area of the conductor in circular mils. The term mil means one-thousandth (1/1000). For example, a millivolt equals 1/1000 volt. In our money system, one mill (mil) equals 1/1000 dollar. Therefore, in the English System of measurement, a mil is one-thousandth of an inch,(.001 inch).

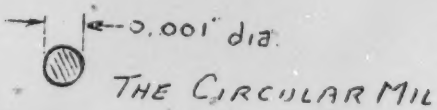

FIG. 1 THE CIRCULAR MIL

A circular mil is the area of a circle (Fig. 1) whose diameter is one mil (0.001 inch), and is usually written C.M. or cir. mil. As stated before, the cir. mil, is the unit with which the cross-sections of wires and cables are measured, just as the square foot is the unit by which larger areas, such as floors, are measured.

Inasmuch as the areas of circles vary as the squares of their diameters, the area of a wire in circular mils is equal to the square of its diameter expressed in mils. In other words, to obtain the number of circular mils in a solid wire of given diameter, express the diameter in mils and then square it.

EXAMPLE: What is the cross-sectional area in circular mils of a wire whose diameter is 0.025 inches?
This problem involves two operations:
1st - Find the diameter of a wire in mils,
2nd - Square the diameter in mils to find the cross-sectional area of the wire in circular mils.

(a) Diameter in mils = 0.025 x 1000 = 25 mils
(b) Area in circular mils = $(25)^2$ = 625 circular mils (Ans.)

QUESTIONS:

1. Find the diameter in mils and the cross-sectional area in circular mils of a copper wire whose diameter is 0.0403 inches.
2. Find the cross-sectional area of a round wire 64.1 mils in diameter.
3. Find the circular mil area of a wire whose diameter is 0.464 inches.

   To obtain the diameter of a solid wire having a given area in circular mils, take the square root of the circular mils and the answer will be the diameter of the wire in mils.

   Example: A certain wire has a cross-sectional area of 4,107 circular mils. What is its diameter?

   4107 = 64.085 mils = 0.064085 inches (Ans.)

Note: (The following is the method for extracting square root).

```
                4107.000000   64,085
                  36
          124 /  507
                 496
         1280 /  1100
                    0
        12808 /  110000
                 102464
       128165 /   753600
                  640825
```

4. A round solid wire has a cross-sectional area of 10,380 circular mils. What is the diameter in mils?
5. A solid wire has a cross-sectional area of 1624 C.M. What is the diameter?

The Circular - mil - foot

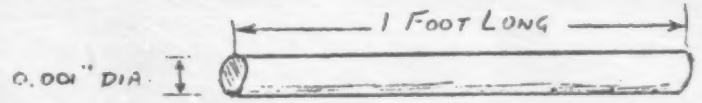

FIG. 3. THE CIRCULAR MIL-FOOT

The Circular Mil-Foot is a unit wire having a cross-sectional area of one circular mil and a length of 1 foot, as shown in Fig. 3.

QUESTIONS (Continued)

Computing the Resistance, when length and area are given:

To find the resistance of a wire, multiply the resistance of a circular mil-foot (K) by its total length in feet, and divide this product by its area in circular mils. This rule, expressed as a formula, becomes:

$$R = \frac{K\,L}{D2}$$

where R = resistance in ohms,
K = resistance of one circular mil-foot in ohms
L = length of the wire in feet,
D^2 = circular mil area of the wire.

The constant 10.8 is generally used in practice because this is the approximate value of "K" for commercial copper at the room temperature of 75°F.

The value of K for other metals may be found by consulting Resistivity Tables given in handbooks.

Example: Find the resistance of 400 feet of copper wire having a cross-sectional area of 4,107 C.M.

Solution: $R = \frac{K\,L}{D^2} = \frac{10.8 \times 400}{4107} = 1.05$ ohms (Ans.)

Computing the Area, when resistance and length are given:

By transposing, the formula may be stated as follows:

$$D^2 - \frac{K\,L}{R}$$

Example: What is the circular mil area of a 1000 foot copper wire if its resistance is 1 Ohm?

Solution: $D^2 - \frac{K\,L}{R} = \frac{10.8 \times 1000}{1} = 10{,}800$ C.M. (Ans.)

Computing the Length, when resistance and area are given:

By transposing, the formula may be stated as follows:

$$L - \frac{R\,D^2}{K}$$

Solution: $L = \frac{3.2 \times 1624}{10.8} = 482$ feet (Ans.)

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PROCEDURE, PART I:

Measure off 50 feet of #28 B & S Copper wire. By use of a micrometer, measure its diameter and record in Table A.

Calculate the resistance of this wire. (Show formula and all calculations). Consult handbooks for the proper value to use for K. Record results in Table A.

Check the resistance of the wire by the Wheatstone Bridge method and record in Table A.

Repeat the experiment using the various conductors listed in Table A.

TABLE A

Size (B & S)	Material	L (feet)	D (Inches)	D (mils)	Area (C.M.)	K	R Calcul.	R Meas.
#28	Copper	50						
#24	Copper	25						
#18	Copper	50						
#18	Aluminum	50						
#18	Iron	50						
#18	Manganin	50						

QUESTIONS (Continued)

6. For each test, how do the "calculated" and "measured" values of resistance compare?

PROCEDURE, PART II:

Using a Wheatstone Bridge, measure the resistance of a coil of wire (see your instructor). Record in Table B. Measure the total length of the wire, Record in Table B.

Calculate the diameter of the wire. (Show formula and all calculations). Record in Table B. By use of the micrometer, check the diameter of this wire. Record in Table B.

TABLE B

Material	L (feet)	R	K	D (mils) (calculated)	D (mils) (measured)

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QUESTIONS (Continued)

7. How do the "calculated" and "measured" values of diameter compare?

PROCEDURE, PART III:

Using a Wheatstone Bridge measure the resistance of a coil of wire (see your instructor). Record in Table C. Using the micrometer, measure the diameter of the wire. Record in Table C.

TABLE C

Material	R	D (mils)	Area (C.M.)	K.	L (calculated)	L (measured)

QUESTIONS (Continued)

8. How do the "calculated" and "measured" values of length compare?
9. What is meant by the term "mil"?
10. What does "circular mil" mean?
11. What is meant by the term "circular mil-foot"?
12. What is meant by the term "specific resistance"?
13. What is the difference, if any, between "specific resistance"and resistivity? What is meant by "conductivity"?
14. What have you discovered in this experiment?
15. Give at least three applications where you, as an electrician, can make use of the fact you have discovered in this experiment.
16. Find the cross-sectional area of a wire 0.2893 inches in diameter.
17. A round wire has a cross-sectional area of 9.89 circular mils. What is its diameter in inches?
18. Find the resistance of 75 feet of #14 B & S copper wire, diameter 0.0641 inches.
19. Find the cross-sectional area, in circular mils, of a stranded conductor made up of seven strands of #12 B & S gauge wire. Each #12 strand has a diameter of 80.8 mils.

QUESTIONS (Continued)

20. A conductor made up of seven strands has a total cross-sectional area of 28,740 C.M. Find the diameter of each strand.

21. Find the resistance of 5 miles of #10 B & S copper wire, diameter 101.9 mils.

22. Find the number of feet of #30 B & S copper wire needed to make a resistance of 200 ohms. #30 wire has a diameter of 10.025 mils.

23. A certain coil of copper wire is 4,381 feet long. What size wire must be used in order that the resistance shall not exceed 480 ohms?

24. Find the resistance of 20 miles of #4 aluminum wire, diameter 0.2043 inches.

25. Find the resistance of 90 feet of #8 copper wire, diameter 0.1285 inches.

26. How many circular mils are there in a solid wire 1 inch in diameter?

27. (a) How many strands of what size wire are used in a #6 stranded wire?
    (b) How many strands of what size wire are used in a #4 stranded wire?
    (c) How many strands of what size wire are used in a #2 stranded wire?

IMPORTANT: These answers should be memorized by the apprentice because they will enable him to identify #6, #4 and #2 wires when practicing his trade.

NOTE: The journeyman electrician is expected, <u>through</u> his experiences at the trade, to be able to identify the various sizes of wire from #18 to #1 <u>without the use of wire gauge or micrometer</u>. In other words, he is expected to be able to tell the size of the commonly used wires by merely looking at and feeling of them, the same as he is expected to be able to tell 1/2 inch, 3/4 inch, 1 inch, 1-1/4 inch, 1-1/2 inch, 2 inch, etc. conduit without actually measuring the diameter.

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1942	Pages 43-45
Lessons in Practical Electricity - Swoope's 1948	Page 112
Elementary Electricity - Slack 1943	Page 56
Elements of Electricity - Timbie 1937	Page 62
National Electrical Code	

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Experiment No. 56
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Use of Wire Tables

PURPOSE:

To learn how to use wire tables.

MATERIALS USED:

Micrometer, wire gauge, wire tables, various sizes of wire.

NOTES AND PROCEDURE - PART I:

Copper wire is ordinarily manufactured only in standard sizes. A number of wire gauges, differing slightly from each other, have been originated by different wire manufacturers. In the United States practically all wire is now sized by the American Wire Gauge (A.W.G.) formerly called the Brown and Sharpe (B & S) gauge, developed by the Brown and Sharpe Manufacturing Co.

A list of the standard sizes, of which only even numbers (excepting the very small sizes) are in general use, may be found in the references.

In Chapter 9, Table 8 of the 1975 Code Book there is a table of the "Properties of Copper Conductors".

The first column shows the gauge number.

The fifth column shows the diameter of each gauge number in inches.

The second column shows the area of cross-section in <u>circular mils</u>.

How is this column calculated?

By use of wire gauge and micrometer, check all the various sizes of wires in the stock crib. Compare your results with Column one and five of the Table 8.

Also for each wire, calculate its cross-sectional area. Compare these calculations with Column 2 of the Table.

Some wire tables give more data concerning wires. Consult the wire table on Page 115 of Swoope's. You will find that in addition to what has already been said, the following is given:
(a) Resistance in ohms per 1000 ft.
(b) Weight in pounds per 1000 ft.

NOTES AND PROCEDURE - PART I (Continued)

The use of these tables greatly simplifies all wire computations.

NOTES AND PROCEDURE - PART II:

The A.W.G. is based on a constant ratio of cross-section between wires of successive gauge numbers. These ratios are given below. If you will remember these ratios, also the resistance and the cross-sectional area of #10 A.W.G. copper wire (given under "a" and "b"), it will not always be necessary to refer to the wire tables because with this knowledge it will be a comparatively simple matter to calculate the cross-section, resistance or weight of any gauge number wire.

Important Data on A.W.G.

(a) The cross sectional area of #10 gauge wire is approximately 10,000 circular mils.

(b) The resistance of 1,000 feet of #10 copper wire is approximately 1 ohm.

(c) The cross-sectional area of the wire grows smaller as the gauge number increases.

(d) To find the cross-sectional area of a wire when that of another is already known, perform the operation indicated in the table below.

If one gauge number lower, multiply the known area by 1.26.

If two gauge numbers lower, multiply the known area by 1.6.

If three gauge numbers lower, multiply the known area by 2.

If ten gauge numbers lower, multiply the known area by 10.

If one gauge number higher, divide the known area by 1.26.

If two gauge numbers higher, divided the known area by 1.6.

If three gauge numbers higher, divide the known area by 2.

If ten gauge numbers higher, divided the known area by 10.

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NOTES AND PROCEDURE - PART II (Continued)

Example #1: What is the cross-sectional area of #12 A.W.G. wire? The cross-sectional area of #10 is approximately 10,000 c.m.

The cross-sectional area of #12 = $\frac{10,000}{1.6}$ = 6,250 c.m. (Ans.)

Example #2: What is the cross-sectional area of #14 A.W.G. wire?

The cross-sectional area of #13 = $\frac{10,000}{2}$ = 5,000 c.m.

One gauge number higher than #13 would therefore be $\frac{5,000}{1.26}$ = 3968 c.m. cross-sectional area of #14 wire (Ans.)

Example #3: What is the cross-sectional area of #4 A.W.G. wire?
Cross-sectional areaof #7 = 10,000 x 2 = 20,000 c.m.
Therefore, cross-sectional area of #4 = 20,000 x 2 = 40,000 c.m. (Ans.)

Example #4: What is the resistance of 1,000 feet of #0 A.W.G. copper wire?

Note: The resistance varies inversely as the cross-sectional area.

Resistance of 1,000 feet of #10 A.W.G. wire is 1 ohm. Therefore, resistance of 1,000 feet of #0 A.W.G. copper wire is:

$\frac{1}{10}$ - 0.1 ohm (Ans.)

Example #5: What is the resistance of 200 feet of #12 A.W.G. copper wire? Resistance of 1,000 feet of #12 A.W.G. copper wire = 1 x 1.6 = 1.6 ohms. Why?

Therefore, resistance of 200 feet of #12 A.W.G. copper wire equals:

$1.6 \times \frac{200}{1000}$ = 1.6 x 0.2 = ohms. Why?

If the answersgiven above are compared with the wire tables, it will be found that the answers are only approximate. However, these answers are close enough for most jobs.

Experiment No. 56
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QUESTIONS:

1. The Allowable Carrying Capacities of Wires must be memorized by the student because his future employer will expect him to know it. What is the allowable current-carrying capacities of #14, #2, #10, #8, #4, #12, #6 rubber covered conductors?
2. What is slow burning wire and where is it used?
3. What is (a) varnished cambric wire, (b) weather-proof wire? Where is each used?
4. What is the material used in THW insulation and where would wire with it be applied?
5. (a) What is lead-covered cable?
   (b) Where is it used?
6. What type of wire would you use:
   (a) On a conduit installation (110/220) under ordinary conditions?
   (b) On conduit installations where the voltage exceeds 600 volts?
   (c) On conduit installations in extremely hot locations?
   (d) On 115/230 volt underground services (conduit)?
7. Is it allowable to use #6 solid wire in conduit? Explain.
8. What type of wire is used to wire fixtures?
9. Is it allowable to use wires insulated with varnished cambric which is smaller than No. 6?
10. In house wiring, may feeders be placed in parallel to obtain desired current carrying capacity? Explain.
11. Why is the allowable carrying capacity for aluminum taken as 84 per cent of those given in the table for the respective sizes of copper wire with the same kind of covering?
12. What is the cross-sectional area of #14 A.W.G. wire?
13. Is there any difference between the cross-sectional area of #14 A.W.G. wire and #14 B & S wire?
14. What size wire would you use to carry 38 amperes? (Assume the current is transmitted but a short distance).
15. Without referring to any tables, find:
   (a) The cross-sectional area of #2 wire,
   (b) The cross-sectional area of #18 wire,
   (c) The cross-sectional area of #6 wire,
   (d) The cross-sectional area of #14 wire,
   (e) The cross-sectional area of #20 wire.

   Show all work.

QUESTIONS (Continued)

16. Without referring to any tables, find the resistance of 1,000 foot of each of the wires in Problem 15. Show all work.
17. What is copper-clad wire? Where used? Why?
18. How is iron wire protected from oxidation?
19. Of what use to electricians are wire tables?
20. If the resistance of 1,000 feet of #10 copper wire is 1.02 ohms, what is the resistance of 1,000 feet of #10 aluminum wire?
21. Calculate the resistance of 1,100, 900, and 800 feet respectively of #10 B & S copper wire. Show all work.
22. What determines the current-carrying capacity of any wire?
23. What does each of the following abbreviations mean?

RHW WIRE	B&S GAUGE	SE CABLE	UL
RUW WIRE	A.W.G.	USE CABLE	MI CABLE
TW WIRE	THWN WIRE	NEC	XHHW WIRE
THW WIRE	THHN WIRE	NEMA	H_z

24. What sizes of T.W. wire would you use to carry:

(a) 53 amps.	(f) 360 amps.
(b) 35 amps.	(g) 23 amps.
(c) 400 amps.	(h) 75 amps.
(d) 99 amps.	(i) 20 amps.
(e) 9.4 amps.	(j) 500 amps.

In each of the above, assume the current is transmitted but a very short distance.

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1942 — Pages 47-48
Lessons in Practical Electricity - Swoope's 1948 — Pages 66-67
Elements of Electricity - Timbie 1937 — Page 68
National Electrical Code

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Tables and Charts

EXPLANATORY NOTES:

Although it is possible, by use of formulas, to calculate the size wire for any circuit (whether it be alternating or direct current), nevertheless, electrical manufacturers, handbooks, etc. have prepared TABLES AND CHARTS by which we are able to find the size wire to use in transmitting a given current (or K.W. load) a given distance with a given voltage drop. These tables and charts have been calculated by using the formula:

$$C.M. = \frac{21.6 \times \text{Amperes} \times \text{Distance in feet}}{\text{Voltage Drop}}$$

or some modification of it (as in the case of 2-phase and 3-phase circuits, etc.).

EXAMPLES: On Page 212 (1936 Edition) of the American Electricians' Handbook, a graph is given by which we are able to read off the size wire to use in transmitting a given load a given distance with a given voltage drop. Consult Page 211 of that Handbook on how to use this graph.

On Page 84 of Kushlan's Handbook of Industrial Electricity, there is a table which shows the wire size required for 115 volt lighting circuits of various lengths of run for various watt loads, based on a drop of 2 volts between the panel board and the outlets.

CAUTION: IN USING TABLES AND GRAPHS TO DETERMINE WIRE SIZES, YOU MUST CAREFULLY STUDY WHAT IS GIVEN. SOME OF THE POINTS WHICH YOU MUST WATCH OUT FOR ARE:

(1) THAT THE SIZE WIRE PRODUCING AN ALLOWABLE VOLTAGE DROP WILL SAFELY CARRY THE CURRENT. Also, that the N.E.C. requirement in regard to using not smaller than #14 R.C. for branch circuits is not violated, that no service wire is smaller than #8 R.C., etc.

EXPLANATORY NOTES (Continued)

EXAMPLE: In a Wiring Table (showing the size wire to use in transmitting a given current a given distance with a 2 per cent drop for 110 volt circuits), furnished in a catalog of a certain electrical manufacturer, the use of #16 A.W.G. wire in transmitting 12 amperes a distance of 20 feet with a drop of 2.2 volts is given. True, #16 wire will produce a drop of only 2.2 volts in this problem, but, #16 wire will carry only 6 amperes. Moreover, #14 is the smallest size allowed by the N.E.C. for a lighting branch circuit. In this particular problem #14 R.C. wire must be used. If these two facts are borne in mind, the table referred to in this paragraph can be used to good advantage. As a matter of fact this particular table adds no more precautions than those you must observe when calculating wire size by the formula given on Page 1.

Another thing to watch out for in selecting tables or charts is whether they will give you what you need.

EXAMPLE: Table 20-X, Page 501 of Kushlan's Handbook of Industrial Electricity, is useful in finding the size wire for various voltage drops when the product of amperes by the one-way distance in feet (Amperes x Length in feet) have first been found. To use this table in finding out what size wire you would use to transmit 20 amperes one hundred feet with a drop of 2 volts, proceed as follows:

(a) Multiply 20 x 100 = 2000 amp.-ft.

(b) Look in the table for the nearest wire size corresponding to 2000 amp.-ft. and a drop of 2 volts. You will find the answer to be #7 A.W.G. wire. As #7 is not standard, #6 A.W.G. wire would be used.

If you thoroughly understand how to figure (by formula) the size wire required to transmit a given current a given distance with a given voltage drop, you will not encounter any difficulty in using the tables and charts described above and similar tables serving the same purpose found in other handbooks, manufacturers' bulletins, etc.

Experiment No. 57
Page 3 of 3

QUESTIONS:

1. By use of the graph on Page 212 (1936 Edition) of the American Electricians' Handbook, find the size wire to transmit:

   (a) 20 amperes, 75 feet with a drop of 1.4 volts.
   (b) 45 amperes, 125 feet with a drop of 2 volts.
   (c) 70 amperes, 500 feet with a drop of 4 volts.

2. For each item under Problem 1, check your answer by use of the formula:

$$C.\ M. = \frac{21.6 \times I \times L}{\text{Voltage Drop}}$$

REFERENCES:

American Electricians Handbook
Kushlan's Handbook of Industrial Electricity

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 58
Page 1 of 2

Measuring Resistance by Substitution Method

PURPOSE:

To measure an unknown resistance by substituting for it known resistance from a resistance box.

MATERIALS USED:

Dry cell, ammeter, two connectors, unknown resistances, resistance box, bell wire for connecting leads.

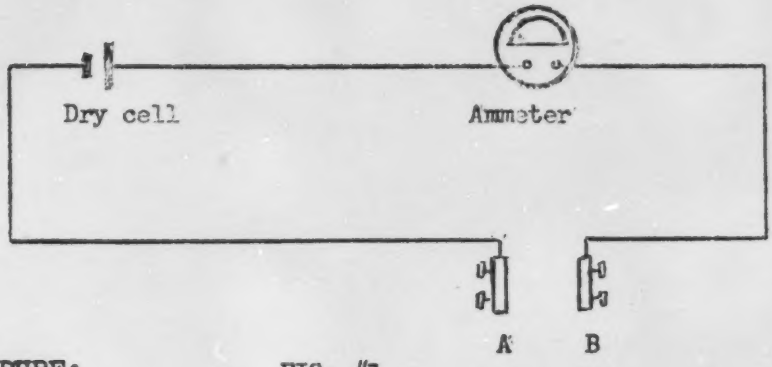

FIG. #1

PROCEDURE:

Connect the apparatus as shown in Fig. 1. Connect an unknown resistance across the connectors "A" and "B". (Use a 50 foot coil of #18 manganin wire for the unknown resistance). Read the ammeter and record in the Table on Sheet 2.

Replace the unknown resistance with a known adjustable resistance (resistance box). Adjust the resistance in the resistance box until the ammeter reads exactly the same as it did with the unknown resistance in the circuit. While adjusting the switches (or plugs), as the case may be, on the resistance box, keep your eye constantly on the ammeter needle. Read and record the setting of the resistance box. This is equal to the resistance of the coil being measured. Check the resistance of the unknown coil three times. In checking, be careful not to look at previous results so that your second and third trials may not be biased by the results of the first. Record all three readings in the last column of the Table. Take the average of the three readings.

PROCEDURE (Continued)

In the same way, measure the resistance of the other three coils listed in the Table. Check the resistance of each unknown coil three times.

TABLE

Material	Cross-Section (By number)	Length (Feet)	Galv. Reading Degrees	Resistance Ohms
Manganin	#18 B & S	50	1st	
			2nd	
			3rd	
Copper	#18 B & S	50	1st	
			2nd	
			3rd	
Iron	#18 B & S	50	1st	
			2nd	
			3rd	
Aluminum	#18 B & S	50	1st	
			2nd	
			3rd	

QUESTIONS:

1. The "method of substitution" for finding resistance is based upon the fact that bodies of equal resistance substituted in the same circuit will transmit the same amount of current. What proof have you had of this fact in preceding experiments?

2. With the connections shown in Fig. 1, the deflection of the meter with an unknown resistance in the circuit was 15 amps. When the standard resistance box was substituted it was necessary to adjust the box for 48.3 ohms to obtain the same meter reading. What is the resistance of the appliance measured?

3. What fact have you discovered in this experiment?

REFERENCES:

Lessons in Practical Electricity -
Swoope's 1948 Page 261

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Ohmmeter

PURPOSE:

To measure resistance by use of an ohmmeter.

MATERIALS USED:

Ohmmeter, several resistors.

EXPLANATORY NOTES:

In previous experiments, you have discovered that volts and amperes can be measured by direct reading instruments (voltmeter and ammeter).

Similarly, there is a commercial instrument, called an ohmmeter, which measures resistance in ohms directly. However, it is not used like a voltmeter or an ammeter. When using an ohmmeter to measure the resistance of a circuit, the source of power to that circuit must be Turned Off. The dry cells contained within the ohmmeter case provide its operating power. The ohmmeter described in this experiment does not have sufficient accuracy for laboratory, but is sufficiently accurate for service work. Also it is very useful for making continuity tests. The advantage of the ohmmeter, over other methods such as the Volt-Ammeter Method for determining resistance, is the speed with which the resistance can be measured.

Fig. 1 shows the basic circuit of one type of Ohmmeter. A known fixed voltage (the dry cells) is connected in series with the meter M, the fixed resistor R2 which is of sufficient value to prevent meter damage, and the resistance Rx to be measured. The variable resistor R1 is so adjusted that exactly full-scale deflection on the meter scale is obtained when the test prods are touched together.

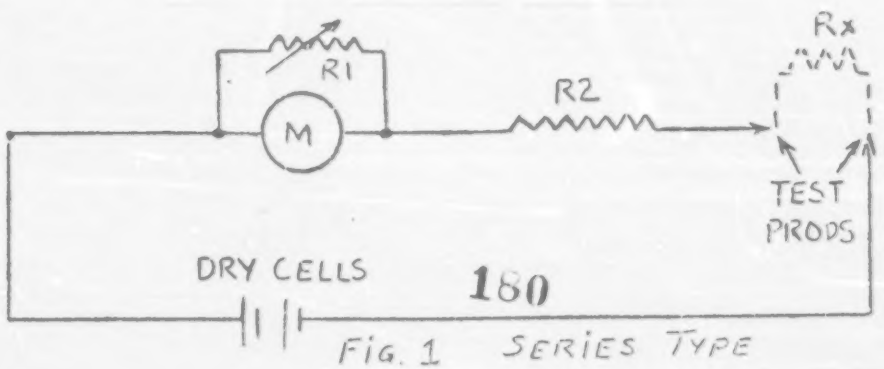

Fig. 1 SERIES TYPE

EXPLANATORY NOTES (Continued)

The meter "M" is a milliammeter, the scale of which is calibrated directly in ohms. When Rx is inserted in the circuit (Fig. 1), the meter will indicate a lower value on its scale, depending upon the ohmic resistance of Rx.

The type of ohmmeter shown in Fig. 1 is called the series type because the dry cells, meter and the resistance to be measured are in series. In this type of ohmmeter "0" ohms is at the right of the meter scale (see Fig. Ia), and the highest resistance value which this ohmmeter can read (Example 500,000 ohms) is at the left side of the scale. Note: This is just the reverse of the ordinary meter scale. The series type is suitable for measuring medium and high resistance values.

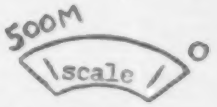

FIG. # 1A

Before using the ohmmeter, the "zero adjustment" is made by holding the test prods together and adjusting the resistor R1 until the pointer registers zero ohms. It is absolutely necessary to make this "zero adjustment" each time because the voltage of the dry cells change with age and use. In order to have the instrument read correctly, the proper current must flow through the element of the milliammeter. (Note: If the pointer cannot be set on zero, with a full rotation of the battery needs replacing). The test prods are then separated and the ohmmeter is ready for use. When making a resistance measurement, the test prods are connected across the resistance to be measured (Rx in Fig. 1)

LOW RANGE OHMMETER

For measuring low values of resistance a shunt type ohmmeter is used. The basic circuit is shown in Fig. 2. With this type of ohmmeter, the unknown resistance Rx to be measured is connected in parallel with the meter.

EXPLANATORY NOTES (Continued)

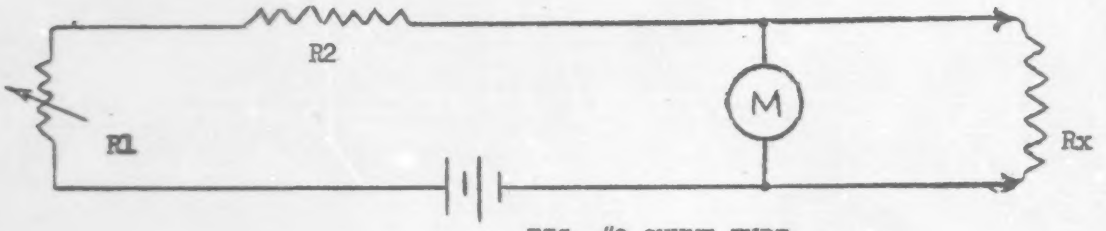

FIG. #2 SHUNT TYPE

Before taking a resistance measurement, adjust the variable resistor R1 until the meter reads full-scale with the test prods separated.

If the test prods are held together the meter is shorted out. When the test prods are connected to Rx, the unknown resistance being measured, a lower meter reading results because Rx diverts a portion of the current from the meter. With the shunt type ohmmeter zero ohms is at the left on the scale. This is exactly opposite to a series ohmmeter.

Often these instruments are provided with multipliers and shunts so that it can be used as a voltmeter or milliammeter of several ranges in addition to being used as an ohmmeter. Such combination instruments are known under various names such as, Volt-ohmmeter, Volt-Ohm-Milliammeter, Multimeter, Multitester, When making voltage or current measurements the battery is disconnected by a switch built into the case.

PROCEDURE:

Measure several unknown resistances by using an ohmmeter. Follow instructions furnished with the meter.

QUESTIONS:

1. What is an ohmmeter?
2. Describe the construction and operation of the ohmmeter assigned to you.
3. What preliminary check do you have to make before using an ohmmeter?
4. Explain how to make the "zero adjustment" on (a) series type ohmmeter, (b) shunt type ohmmeter.
5. How can you distinguish a shunt type ohmmeter from a series type by an inspection of the ohmmeter scale?

Experiment No. 59
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REFERENCES:

Lessons in Practical Electricity - Swoope's 1948 — Pages 272-276
Elements of Electricity - Timbie 1937 — Page 90
Manufacturers' Bulletins

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 60
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Measuring Resistance by Fall of Potential Method

PURPOSE:

To determine the resistance of an unknown substance by comparing the voltage drop across the unknown resistance with the voltage drop across a known resistance in series with it.

MATERIALS USED:

Storage battery, low reading voltmeter, voltmeter drop leads, standard resistances, several unknown resistances, variable resistance for controlling the current, S.P. switch.

SKETCH:

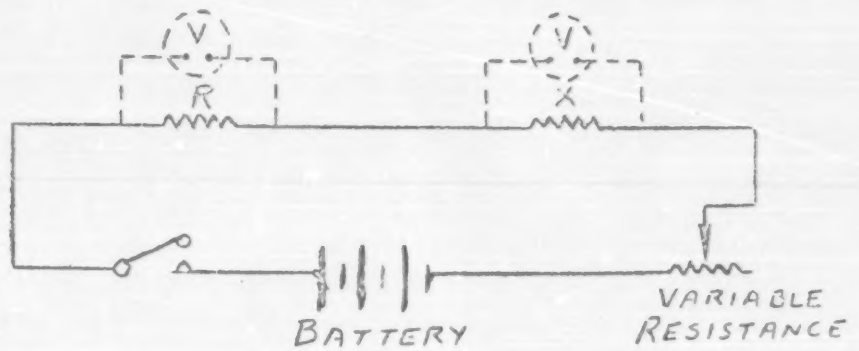


Fig. 1

PROCEDURE:

Connect the apparatus as shown in Fig. 1. Connect the voltmeter across R (the known resistance). Adjust the variable resistance until the voltmeter reads about half scale. Read the voltmeter to the nearest tenth of a division. Call this voltage V_R, and record in the table below. As quickly as possible, change the voltmeter leads to read the voltage across X (the unknown resistance). Again, read the voltmeter to the nearest tenth of a division. Call this voltage V_X, and record in the table. Take three sets of readings with three different values of current. By means of the formula, calculate the value of the unknown resistance for each reading, and obtain the average value by adding the three readings and dividing by three. Repeat, using several other unknown resistances. Record readings in table below:

TABLE

Unit Under Test	Voltage Across Known Resistance (V_R)	Voltage Across Unknown Resistance (V_X)	Known Resistance (R) (Ohms)	Unknown Resistance $X = \frac{R \times V_X}{V_R}$ (Ohms)
#1				
#2				
#3				

QUESTIONS:

1. Does the same current flow through the unknown resistance that passes through the standard or known resistance? Why?

2. Why is it true that, in a series circuit, the voltage drop across each part of the circuit is directly proportional to resistance of that part of the circuit?

   Information:

   Since it is true that, in a series circuit, "the voltage drop across each part of the circuit is directly proportional to the resistance of that part of circuit"; the following formula may be used to compute the unknown resistance (X) in Fig. 1.

   $$\frac{\text{Voltage drop across R}}{\text{Voltage drop across X}} = \frac{\text{Known Resistance R}}{\text{Unknown Resistance X}}$$

   Or, $$\frac{V_R}{V_X} = \frac{R}{X}$$

   Solving, $$X = \frac{R \times V_X}{V_R}$$

3. By use of the above formula, compute each unknown resistance, and tabulate in the last column of the table. Show all calculations on your paper.
4. Why is it not necessary to know the value of the current when finding the unknown resistance by this method?

QUESTIONS (Continued)

5. Give advantages of this method for measuring resistance.
6. List errors which may enter into this method for finding resistance.
7. Why is it necessary that the current be steady while measuring resistance by this method?
8. If the unknown resistance is less than the known resistance, will the voltage across the unknown resistance be greater, or smaller, than the voltage across the known resistance? Why?
9. Why are more accurate results obtained "when the known resistance has a value as near as possible to the supposed value of the unknown resistance"?
10. With suitably selected known resistance, is this method adapted for measuring either high or low resistances with accuracy? Explain.
11. Explain, in detail, how to measure resistance by the Fall of Potential Method.
12. If the voltage drop across a 100 ohm standard resistance is 12 volts, what is the resistance of a coil connected in series if the voltage drop across it is 10 volts?

REFERENCES:

Elements of Electricity - Timbie 1937 Page 81
Monograph B-7 (Weston Elec. Instrument Co. Pages 76-77
Lessons in Practical Electricity
Swoope's 1948 Page 261

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 61
Page 1 of 5

Resistance Measurements: Voltmeter-Ammeter Method (Optional)

PURPOSE:

To become familiar with the proper method for the arrangement of instruments when measuring (a) high resistance (b) low resistance by the voltmeter-ammeter method.

MATERIALS USED:

One 15/150 voltmeter, ammeters of proper range, lamp bank, variable resistance (1000 to 2000 ohms), low resistance (less than one ohm).

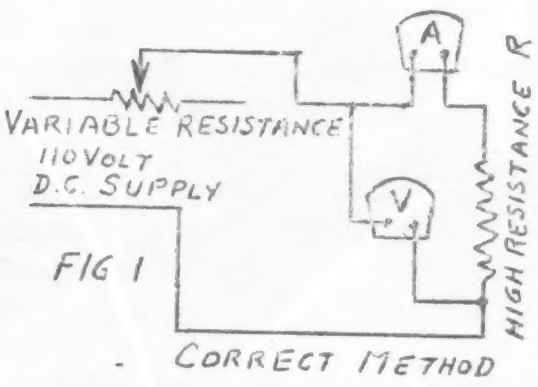


FIG 1
CORRECT METHOD

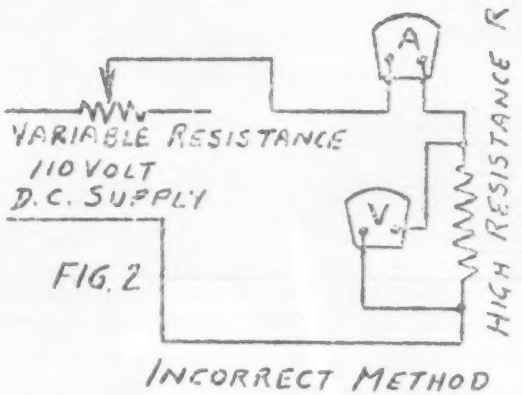


FIG. 2
INCORRECT METHOD

EXPLANATORY NOTES:

The arrangement of voltmeter and ammeter, as shown in Exp. 46 of this unit, applies in most cases when measuring resistance by the voltmeter-ammeter method. In fact, it is the correct method for measuring low or medium value resistance. However, if that method is used in measuring high resistance, a large error may be introduced.

Fig. 1 gives the correct method for measuring high resistance. In Fig. 1, the ammeter reads the true current through the unknown resistance. The voltmeter reading gives the drop across the resistance plus the drop across the ammeter.

Since the resistance of the ammeter is so small compared with the high value of R, the error introduced is negligible, because the drop across the ammeter is very small while the drop across R is nearly equal to the voltmeter reading.

EXPLANATORY NOTES (Continued)

In Fig. 2, the voltmeter reads the true voltage across R, but the ammeter reads the current through R plus the current drawn by the voltmeter. Although the current drawn by the voltmeter is small, nevertheless, it introduces a large error, because the ammeter reading itself is small, and the current taken by the voltmeter may be a large percentage of it. This is due to the fact that both the unknown resistance and the voltmeter resistance are high.

For example: If the resistance of the voltmeter were equal to the resistance of R, half of the current would flow through the voltmeter, thereby introducing an exceedingly large error. The voltmeter should be connected outside the ammeter in this case. (Fig. 1)

PROCEDURE:

Using a high resistance for R, connect as shown in Fig. 1 (Correct Method). Close the switch and adjust the variable resistance until rated current flows through the resistance "R" under test. Read the voltmeter and ammeter and record the readings in Table 1. Take at least three sets of readings with different voltage across R.

Repeat, with connections as shown in Fig. 2 (Incorrect Method).

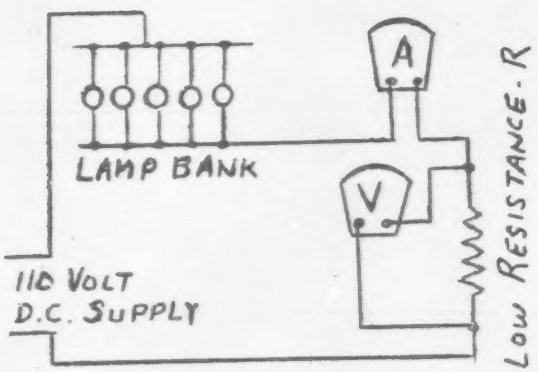
Table I - Data and Calculations - High Resistance

Method	Voltmeter Read. (Volts)	Ammeter Read. (Amperes)	Calculated Resist. (Ohms) $R = \frac{E}{I}$	Resist. Stamped on Spool (Ohms)
Correct (Fig.1)				
Incorrect (Fig.2)				

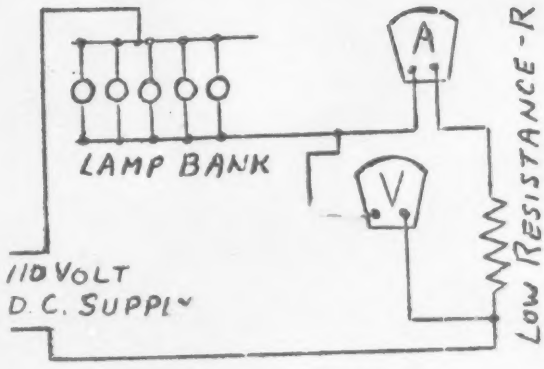
QUESTIONS: - PART I

1. Calculate the resistance for both the correct and the incorrect methods. Tabulate in the Table I.
2. Does it make any difference where the voltmeter is placed when measuring a high resistance?
3. If there is any difference in the results, how do you account for it? Explain.

QUESTIONS - PART I (Continued)



CORRECT METHOD
FIG. 3



INCORRECT METHOD
FIG. 4

EXPLANATORY NOTES:

Fig. 3 gives the correct method for arranging the voltmeter and ammeter to measure <u>low resistance</u>. In Fig. 3, the voltmeter reads the true voltage across R. The ammeter reads the current flowing through both resistance R and the voltmeter. But, since the resistance of the voltmeter is high compared to the resistance R, only a very small current will flow through the voltmeter. In most cases the current drawn by R will be large. Hence, the very small current taken by the voltmeter, causes the error to be negligible.

In Fig. 4, the ammeter reads the true current flowing through R. But, the voltmeter reads not only the voltage across R, but also includes the drop across the ammeter.

Since the ammeter and the resistance R each has a low resistance, the drop across the ammeter may be a relatively large percentage of the voltmeter reading. This error, introduced into the voltmeter reading, would cause a relatively large error in the resistance measurement. In this case, the voltmeter should be connected <u>inside</u> the ammeter. (Fig. 3)

Experiment No. 61
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PROCEDURE:

Using a low resistance for R, connect as shown in Fig. 3 (Correct Method). Close the switch. Screw lamps in the lamp bank until the ammeter reads the rated current of the resistance spool being measured. Read the voltmeter and ammeter and record the readings with different values of current.

Repeat with connections as shown in Fig. 4 (Incorrect Method).

Table II - Data and Calculations - Low Resistance

Method	Voltmeter Read. (Volts)	Ammeter Read. (Amperes)	Calculated Resist. (ohms) $R = \frac{E}{I}$	Resist. Stamped on Spool (Ohms)
Correct (Fig.3)				
Incor-rect (Fig.4)				

QUESTIONS (Continued) PART II

4. Calculate the resistance for both the correct and the incorrect methods. Tabulate in the above table.
5. Does it make any difference where the voltmeter is placed when measuring a low resistance?
6. If there is any difference in the results, how do you account for it? Explain.
7. Where would you place the voltmeter when measuring:
   (a) a high resistance? Why? Include a sketch in your answer.
   (b) a low resistance? Why? Include a sketch in your answer.
8. In <u>most</u> cases where would you place the voltmeter? Why? Include a sketch in your answer.
9. What have you discovered in this experiment?
10. Of what value to you is this fact that you have discovered?

QUESTIONS (Continued)

11. Fill in the blank spaces in the table below. In the second column, state whether voltmeter is inside or outside the ammeter. In the third column make a wiring diagram.

Measuring Resistance: - Voltmeter-Ammeter Method

Unknown Resistance	Voltmeter Connection (With ref. to Ammeter)	Sketch
High		
Low		
Medium		

REFERENCES:

Elements of Electricity - Timbie 1937 Page 78

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Megger

PURPOSE:

To measure insulation resistance by use of the megger, to help one detect, diagnose and forestall trouble in electrical equipment.

MATERIALS USED:

Megger, several pieces of equipment, megger cards.

EXPLANATORY NOTES:

In previous experiments you have discovered that an ohmmeter is a self-contained power unit of low voltage, capable of reading resistance direct. The megger is not intended for measuring resistance direct. Its primary purpose is to detect, diagnose and forestall insulation defects and failures before troubles occur.

CAUTION: Do not use a "megger" whose terminal or operating voltage is in excess of that which is safe to apply to the equipment to be tested.

APPARATUS TO BE TESTED MUST BE DISCONNECTED FROM THE SOURCE OF POWER. NEVER TEST A LIVE CIRCUIT WITH THE MEGGER.

PROCEDURE:

1. Check testing leads with leads connected to the instrument terminals and with opposite ends separated, turn the crank at normal speed. If the pointer indicates less than infinity, there is a leak between the leads which must be removed before proceeding with tests. Touch together the test ends of the leads while turning the crank to make certain by zero reading that the leads are not open-circuited.

2. For testing to ground; Connect from the line terminal to a conductor of the apparatus, and from the Earth terminal to frame of machine, sheath of cable or to a good ground.

   Crank megger and observe scale reading.

3. For testing between two conductors: Connect test leads to the two conductors.

   Crank megger and observe scale reading.

PROCEDURE (Continued)

4. Testing for continuity or locating wires:
   (a) Ground the unknown wire to some common conductor.
   (b) Clip Earth terminal to a common conductor.
   (c) Clip line terminal to unknown wire.
   (d) Crank megger and observe reading.
   (e) If meter does not read low, continue testing other conductors until a low reading is observed - if none - cable must be replaced.

QUESTIONS:

1. What is a megger?
2. What preliminary checks do you have to make before using a megger?
3. Name some practical uses that the megger can be used for to aid the electrician.
4. Describe the construction and the operation of the megger.
5. When reading between two conductors, what does a low reading indicate?
6. What does the N.E.C. require the insulation to ground to be for 14 wire, carrying 8 amps?

REFERENCES:

Direct Current Fundamentals - Loper Pages 116-118
Megger Instruction Manual

CONNECTICUT VOCATIONAL-TECHNICAL SCHOOLS
Electrical Experiments

Experiment No. 63
Page 1 of 8

Measuring Resistance by the Wheatstone Bridge Method

PURPOSE:

(1) To study the construction and operation of a model Wheatstone Bridge.

(2) To measure the resistance of a conductor by use of this Wheatstone Bridge.

MATERIALS USED:

Dry cell, galvanoscope, galvanometer, two keys, resistance box, bodies whose resistances are to be measured, connecting wires, incandescent lamps, voltmeter, four receptacles.

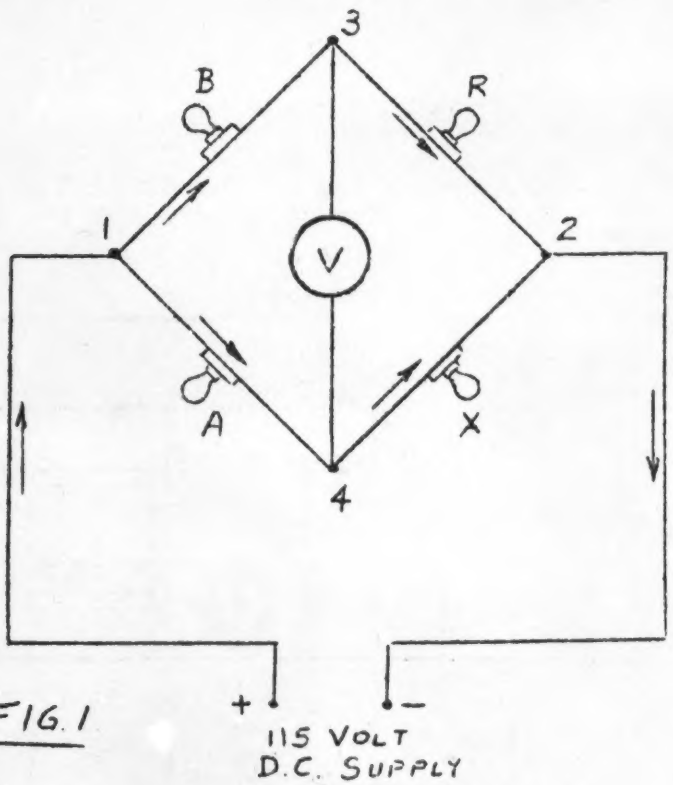

FIG. 1

PROCEDURE:

Part 1 - LAMP ANALOGY OF THE WHEATSTONE BRIDGE.

Trial 1. Connect the apparatus as shown in Fig. 1. R, B, X, and A are 50 watt, 115 volt lamps connected in multiple series so as to form the four arms of the Wheatstone Bridge.

PROCEDURE (Continued)

Apply 115 volts D.C. across the points. Note the brilliancy of each lamp. Read, and record in Table 1 the voltage across each lamp. Also, connect a voltmeter across 3 and 4 as shown. Note and record its reading.

Trial 2. Replace the lamp "R" by a 100 watt, 115 volt incandescent lamp. Note the brilliancy of each lamp. Read, and record in column 2 of the Table, the voltage across each lamp. Note and record the reading of the voltmeter connected across 3 and 4.

Repeat with the following arrangement:

Trial 3. One 50 watt, 115 v. lamp between 2 and 3.
Two 50 watt, 115 v. lamps in parallel between 2 and 4.
Two 50 watt, 115 v. lamps in series between 1 and 3.
One 50 watt, 115 v. lamp between 1 and 4.

Note the brilliancy of each lamp. Note, and record the voltage across the points:

1 - 3
1 - 4
2 - 3
2 - 4
3 - 4

Trial 4. Repeat with one of the 50 watt lamps removed from the parallel combination across 2 and 4. Record your data in Table 1.

TABLE I

Trial No.	(1) Four Arms of the Bridge (Lamps)				(2) Voltage Drops					(3) Four Resistance (Ohms)				(4) Bridge Balance
	R	B	X	A	1-3	1-4	2-3	2-4	3-4	R	B	X	A	$\frac{R}{B} = \frac{X}{A}$
1	One 50 w.	One 50 w.	One 50 w.	One 50 w.						260	260	260	260	
2	One 100 w.	One 50 w.	One 50 w.	One 50 w.						130	260	260	260	
3	One 50 w.	Two 50w. (Series)	Two 50w. (Parallel)	One 50 w.										
4	One 50 w.	Two 50 w. (Series)	One 50 w.	One 50 w.				195						

QUESTIONS - PART I:

1. Carefully study your recordings in Table 1. For each test, when the voltage across 1-3 equals the voltage across 1-4, and the voltage across 2-3 equals the voltage 2-4, what is the voltage across 3-4?
2. When the voltage across 1-3 does not equal the voltage across 1-4, and the voltage across 2-3 does not equal the voltage across 2-4, does the voltmeter across 3-4 show any indication?
3. Assume the resistance of each 50 watt lamp is 260 ohms, and the resistance of the 100 watt lamp is 130 ohms, calculate the resistance of each arm of the bridge and record in column 3 of Table 1.
4. For each test performed, divide the resistance "R" by the resistance "B". Also divide the resistance "X" by the resistance "A". If "R" divided by "B" equals "X" divided by "A", record "Yes" in column 4 of Table 1.
5. Carefully study Table 1: when $\frac{R}{B} = \frac{X}{A}$ what is the reading of the voltmeter across 3-4?
6. If the voltmeter across 3-4 shows an indication, does the formula $\frac{R}{B} = \frac{X}{A}$ hold true?

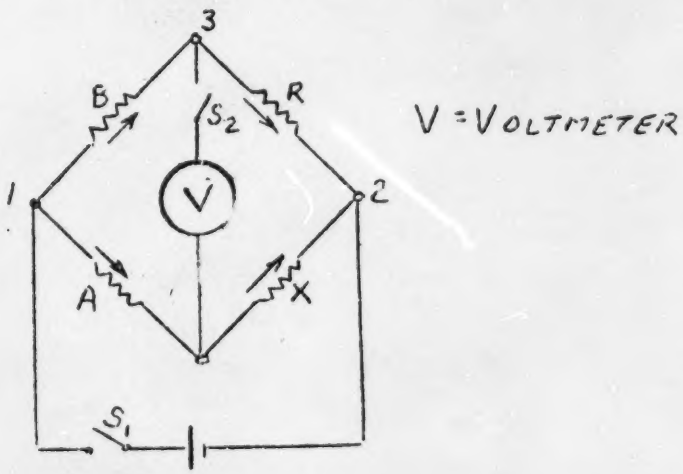

FIG. 2

PROCEDURE:

Part II - OPERATION OF A MODEL WHEATSTONE BRIDGE.

Trial 1. Instead of using lamps, use four 6 ohm coils for the four arms of the Bridge as shown in Fig. 2. Connect a voltmeter across 3 and 4, and a dry cell across 1 and 2. Close the switch S_1. Next close the

PROCEDURE - PART II (Continued)

switch S_2. Does the voltmeter deflect? Open the switches.

Trial 2. Replace the coil at "R" by a 4 ohm coil. Close the switch S_1. Close the switch S_2. Does the voltmeter deflect? Open the switches.

Trial 3. For the four arms of the bridge:

Let R equal 12 ohms
B equal 6 ohms
X equal 8 ohms
A equal 4 ohms

Close the switch S_1. Next, close the switch S_2. Does the meter deflect? Record your observations in Table II.

TABLE II

Trial	Resistance of the Four Arms of the Bridge				Does the voltmeter deflect?	Does $\frac{R}{B} = \frac{X}{A}$
	R	B	X	A		
1	6 ohms	6 ohms	6 ohms	6 ohms		
2	4 ohms	6 ohms	6 ohms	6 ohms		
3	12 ohms	6 ohms	8 ohms	4 ohms		

QUESTIONS - PART II:

7. For each test performed in Part II, determine whether or not

$$\frac{\text{Resistance R}}{\text{Resistance B}} = \frac{\text{Resistance X}}{\text{Resistance A}}$$

and write "Yes or No" in the last column of Table II.

8. (a) In Part I did you, or did you not, find that $\frac{R}{B}$ equaled $\frac{X}{A}$ only when the voltage across 3 and 4 was zero?
Consult Table I.

(b) In Part II does not, $\frac{R}{B}$ equal $\frac{X}{A}$ only when the voltmeter shows no deflection? (Consult Table II).

EXPLANATORY NOTES:

Parts I and II represent the principles upon which the Wheatstone Bridge operates. The Wheatstone Bridge consists essentially of a loop of four resistances, R, B, X, and A. A sensitive voltmeter is connected across 3 and 4. A battery is connected across 1 and 2.

The theory of the bridge is as follows:

Referring to Figs. 1 and 2, the current flows into the loop at "1". Assume the voltage across 3-4 is zero (no current flows between 3-4). At point "1", the current divides so that one part, I_1, goes through B and R and the other part, I_2, goes through A and X; the current from both branches uniting at point "2" to return to the battery.

By Ohm's Law: $E = I \times R$

The same current flows through B as through R. Why? Let us call this current I_1. The current through A and X we will call I_2. The same current flows through A as through X. Why? Therefore:

The voltage across 1-3 equals $I_1 \times B$
The voltage across 1-4 equals $I_2 \times A$
The voltage across 2-3 equals $I_1 \times R$
The voltage across 2-4 equals $I_2 \times X$

Referring to Fig. 1, you found when the voltmeter across 3-4 read zero, the voltage across 1-3 was equal to that across 1-4. Also, the voltage across 2-3 was equal to that across 2-4. Therefore:

$$(1) \quad I_1 \times R = I_2 \times X$$

$$\text{also } (2) \quad I_1 \times B = I_2 \times A$$

Dividing equation (1) by equation (2) there results:

$$\frac{I_1 \times R}{I_1 \times B} = \frac{I_2 \times X}{I_2 \times A}$$

Cancelling I_1 from the left hand member and I_2 from the right hand member, there results:

$$(3) \quad \frac{R}{B} = \frac{X}{A}$$

From this fundamental equation of the Wheatstone Bridge, if we know A, B, and R, we can compute X thus:

$$X = \frac{A}{B} \times R$$

QUESTIONS (Continued)

9. Above is shown the derivation of the formula $\frac{R}{B} = \frac{X}{A}$.

Explain how Parts I and II illustrate that this formula holds true only when the Bridge is balanced. The bridge is said to be "balanced" when there is no flow of current between 3 and 4.

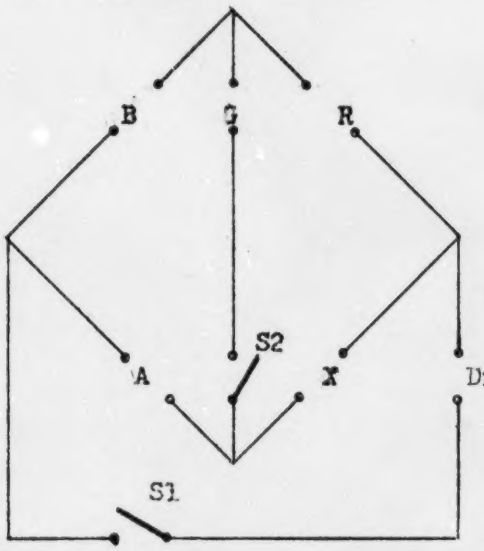

FIG. # 3

PROCEDURE - PART III:

Construct a model Wheatstone Bridge, using strips of copper for conductors, and providing suitable gaps, at A, B, R, and X for the insertion of the resistance coils and the unknown resistance; at G for inserting a galvanometer; and for a dry cell where shown. Install two key switches at S_1 and S_2, and insert a galvanometer at G.

CAUTION: CONSULT YOUR INSTRUCTOR BEFORE USING THE GALVANOMETER. THIS IS AN EXPENSIVE INSTRUMENT. EASILY "BURNED OUT". <u>USE A SHUNT IN CONNECTION WITH THE GALVANOMETER</u>.

In Parts I and II you discovered that the formula $\frac{R}{B} = \frac{X}{A}$ held true only when there was <u>no deflection</u> of the galvanometer, when connected <u>across 3 and 4</u>. Since the unknown resistance is calculated from this formula, the resistance in the arms A, B, and R must be so adjusted that no current will flow through the galvanometer connected across 3 and 4. Proceed as follows to balance the bridge:

PROCEDURE (Continued)

Place the unknown resistance at "X". Connect a 10 ohms spool in an arm A and a 10 ohm spool in arm B. Connect a variable resistance box across R. Make sure all connections are bright and tight.

Depress the battery key S_1. Next, depress the galvanometer key S_2, being ready to release it at once if the galvanometer tends to deflect violently. Note the direction of deflection of the galvanometer needle, that is, to the right or to the left. For example, suppose the needle deflects to the right. Release the galvanometer key. Add more resistance to the arm R. Again note the galvanometer deflection. If it is still to the right, but less than before, release the galvanometer key and add more resistance to the arm R. Again depress the galvanometer key. Suppose, this time, the needle deflects to the left. This indicates that too much resistance has been added to the arm R. Hence, some of the resistance in that arm must be "cut out". Proceed in this manner until the galvanometer shows no deflection. Record the value of the resistance of A, B, and R.

Repeat the experiment by using other values of resistance for A and B. For example, use 10 ohms for A and 100 ohms for B.

Measure the resistance of several bodies, whose resistances are unknown, and record your data in Table III.

TABLE III

	A	B	R	X
Coil	Ohms	Ohms	Ohms	Ohms
#1				
#2				
#3				
#4				

QUESTIONS - PART III:

10. Find the resistance of each coil and record in Table III. Show all work.
11. (a) What is a Wheatstone Bridge?
    (b) What is it used for?
12. Explain the fundamental principle of the Wheatstone Bridge. Include a sketch of your discussion.

QUESTIONS - PART III (Continued)

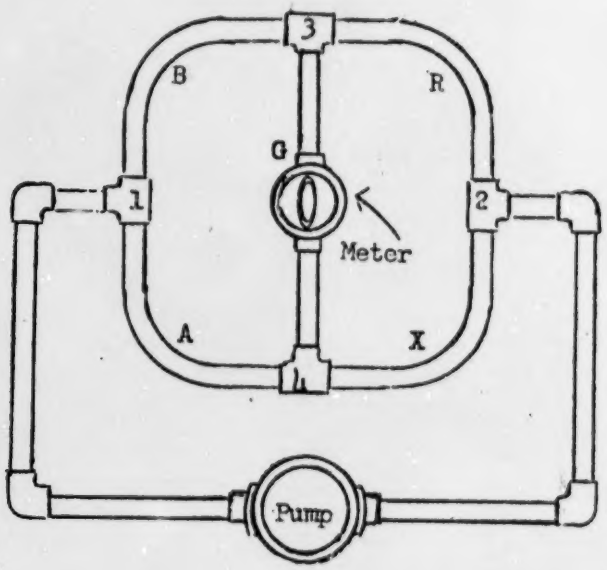

FIG.# 4

13. Explain how this piping system, Fig. 4, illustrates the Wheatstone Bridge. Also indicate by arrows the flow of water through the system. When no water is flowing through the pipe "G", are 3 and 4 at the same level (same pressure)? Is the difference of pressure the same between 1 and 3 as between 1 and 4? Also, is the difference of pressure the same between 2 and 3 as between 2 and 4?

14. What new fact have you learned in this experiment?

REFERENCES:

Elementary Electricity & Magnetism - Jackson & Black 1942	Pages 186-190
Lessons in Practical Electricity - Swoope's 1948	Page 264
Elementary Electricity - Slack 1943	Page 49
Elements of Electricity - Timbie 1937	Page 83